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(54) **FUEL INJECTION VALVE**

(71) Applicant: **HITACHI AUTOMOTIVE SYSTEMS, LTD.**, Hitachinaka-shi, Ibaraki (JP)

(72) Inventors: **Masaki Nagaoka**, Maebashi (JP); **Nobuaki Kobayashi**, Maebashi (JP); **Ryuta Kinoshita**, Mito (JP)

(73) Assignee: **HITACHI AUTOMOTIVE SYSTEMS, LTD.**, Hitachinaka-Shi (JP)

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(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,945,877 A * 8/1990 Ziegler F02M 51/061 123/472
6,170,763 B1 1/2001 Fuchs et al.
(Continued)

FOREIGN PATENT DOCUMENTS

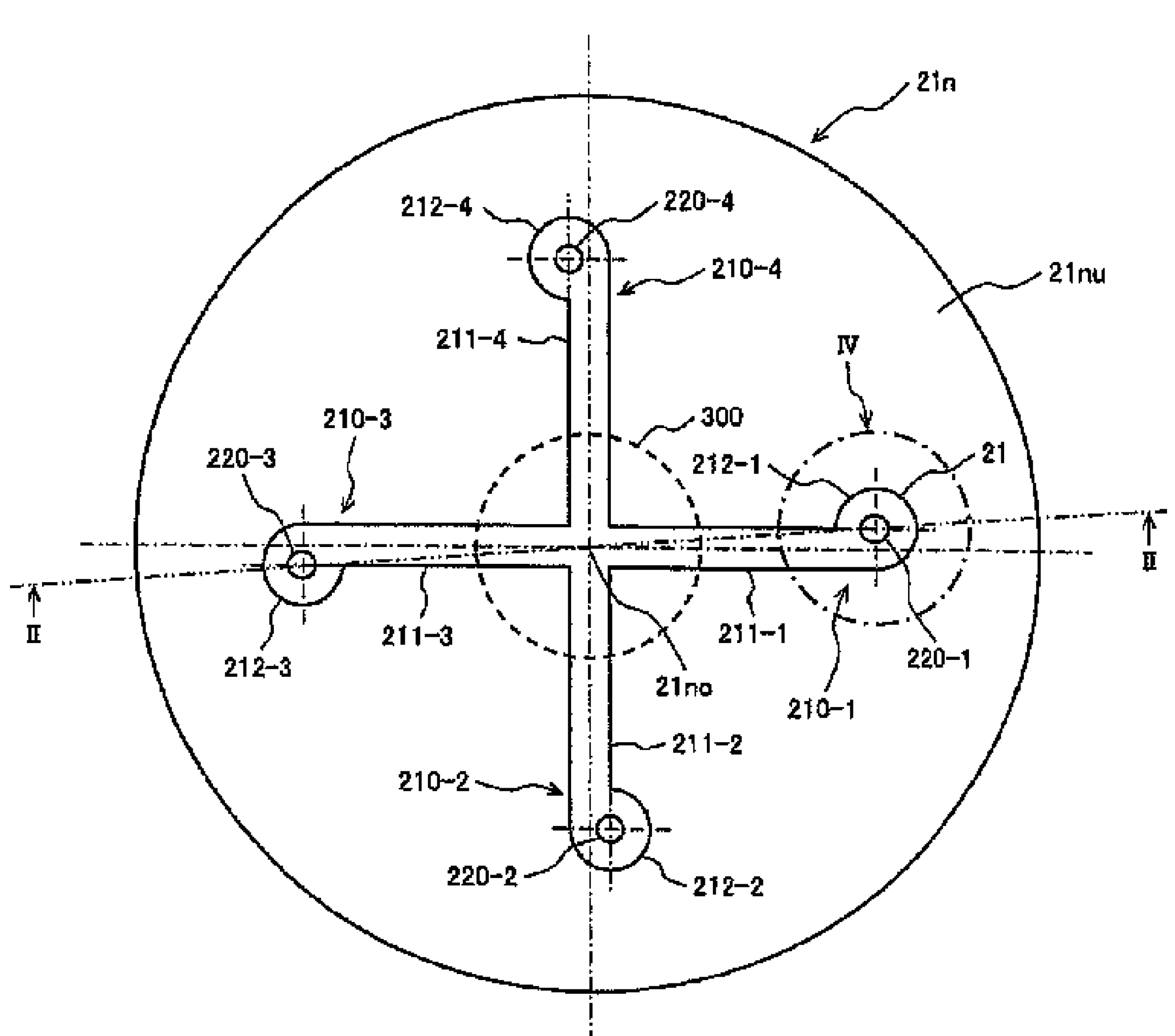
DE 10 2012 213 086 A1 1/2013
EP 2 690 277 A1 1/2014
(Continued)

Primary Examiner — Alex M Valvis
(74) *Attorney, Agent, or Firm* — Foley & Lardner LLP

(57) **ABSTRACT**

Disclosed is a fuel injection valve comprising: a fuel injection orifice provided in a downstream side of a valve seat which a valve body moves toward and away from; a swirl chamber having a swirl passage formed around the entry opening of the fuel injection orifice; and a transverse passage whose end is opened in an inner circumferential wall of the swirl chamber in order to provide a fuel into the swirl chamber, wherein a center of the entry opening is shifted from a first position where the velocity component in the swirl direction of the fuel can be maximized to a second position where the velocity component in the swirl direction is reduced, and where a velocity component in a center axis direction of the fuel injection orifice is enhanced. Thereby, it is possible to easily adjust a fuel injection amount and a spray angle.

6 Claims, 11 Drawing Sheets



(51) **Int. Cl.**
F02M 51/06 (2006.01)
F02M 63/00 (2006.01)

(52) **U.S. Cl.**
CPC ***F02M 61/162*** (2013.01); ***F02M 61/18*** (2013.01); ***F02M 61/1853*** (2013.01); ***F02M 63/0031*** (2013.01)

(58) **Field of Classification Search**
USPC 239/463, 468, 494, 497, 533.12
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,405,945 B1 * 6/2002 Dobrin F02M 51/061 239/463
6,854,670 B2 * 2/2005 Sumisha F02M 51/0678 239/468
8,882,003 B2 11/2014 Okamoto et al.
9,157,403 B2 * 10/2015 Saito F02M 61/162
2003/0141385 A1 * 7/2003 Xu F02M 61/162 239/463
2004/0217204 A1 * 11/2004 Sugimoto F02M 61/162 239/494
2012/0193566 A1 8/2012 Yasukawa et al.
2014/0251262 A1 * 9/2014 Okamoto F02M 61/162 123/306
2014/0251264 A1 * 9/2014 Okamoto F02M 63/0078 123/306

FOREIGN PATENT DOCUMENTS

JP H07-035001 A 2/1995
JP 2000-508739 A 7/2000
JP 2003-336562 A 11/2003
JP 2004-340121 A 12/2004
JP 2006-029131 A 2/2006
JP 2012-158995 A 8/2012
JP 2014-031758 A 2/2014

* cited by examiner

FIG. 1

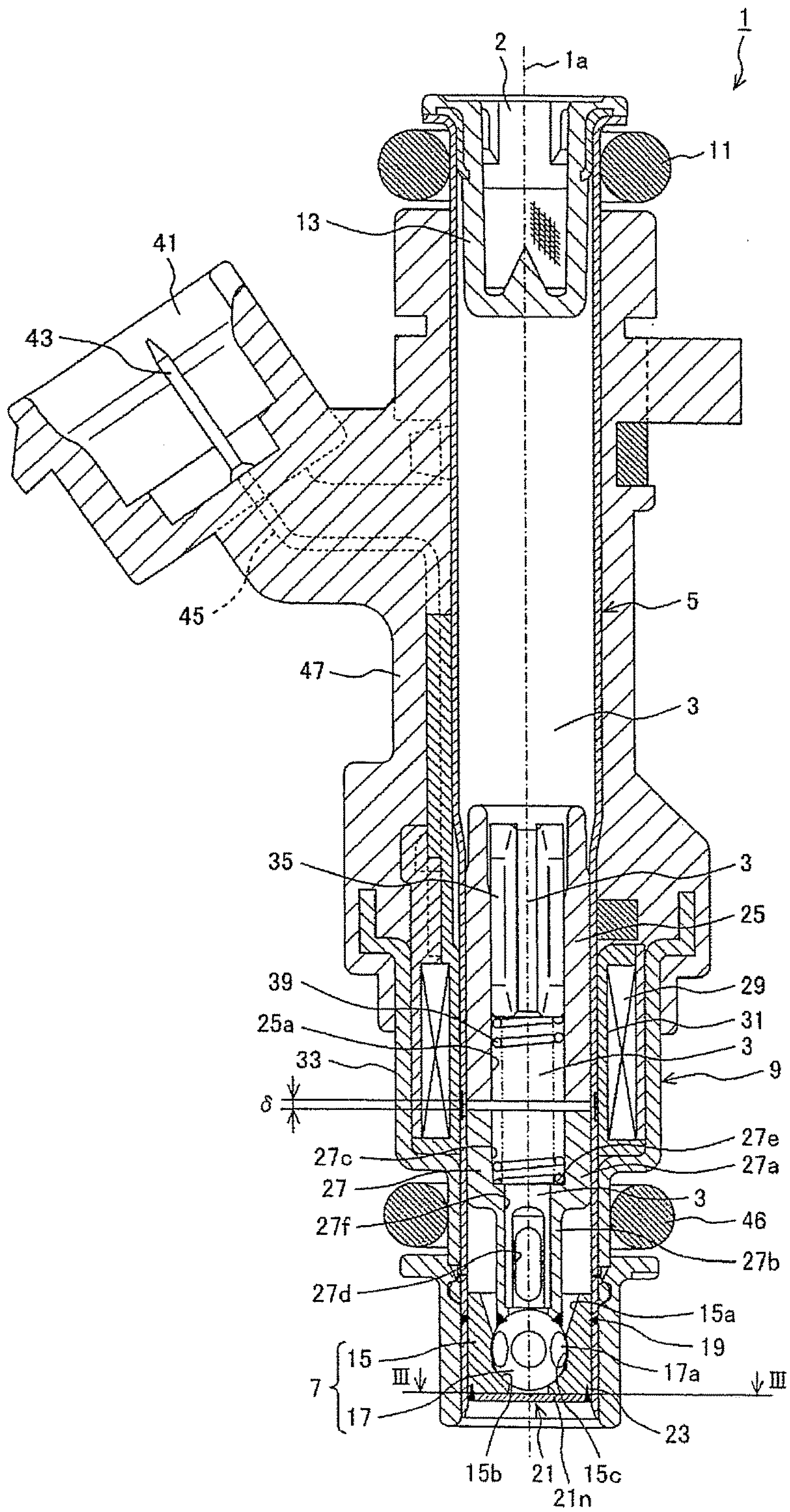

1
2
1a
11
13
41
43
45
5
47
3
35
3
25
39
29
25a
31
3
33
9
δ
27c
27e
27a
27
3
27f
46
27b
27d
15a
19
15
17a
III
III
7
17
23
15b
21
15c
21n

FIG.2

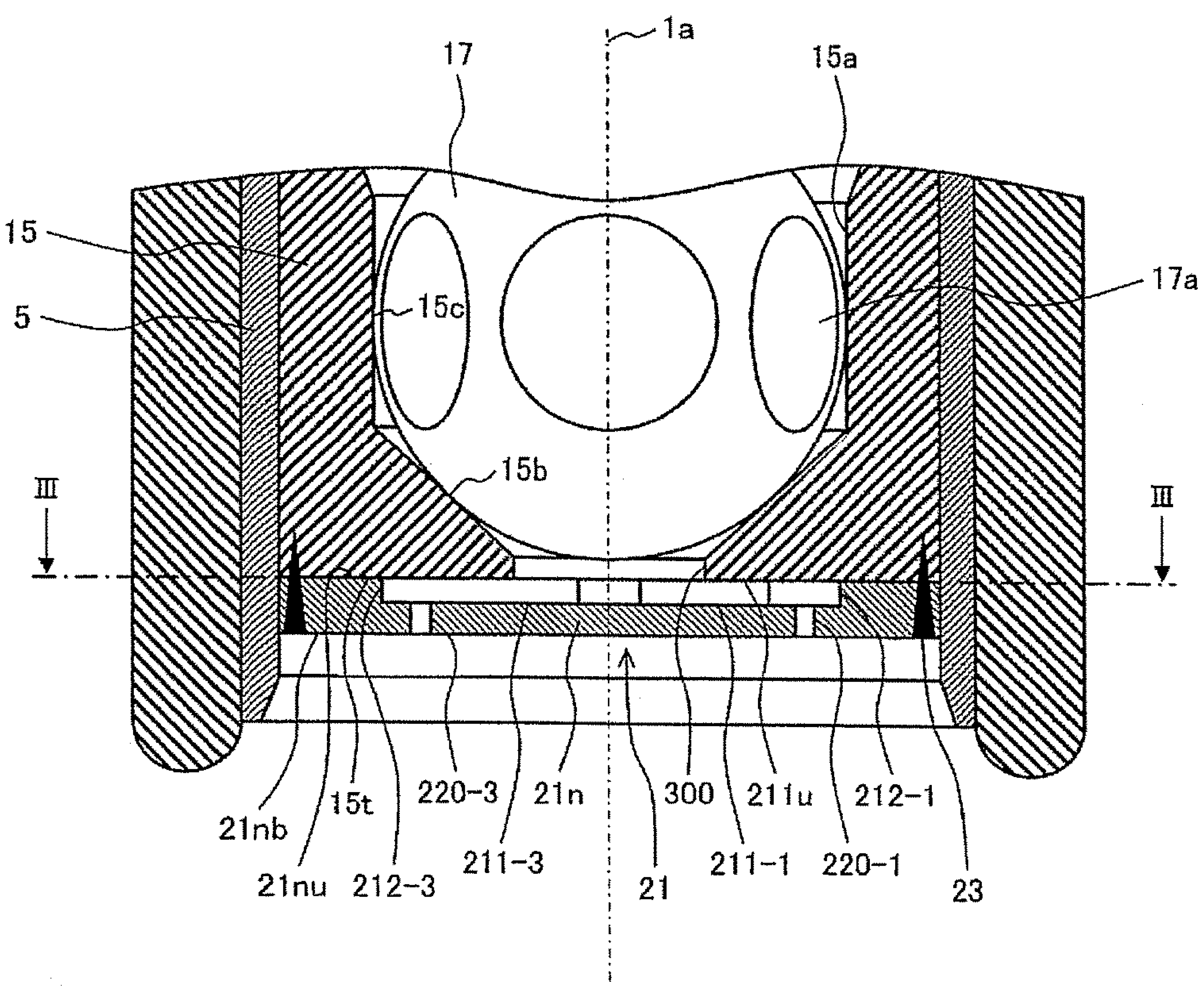

1a
17
15a
15
5
15c
17a
15b
III
III
21nb
15t
220-3
21n
300
211u
212-1
21nu
212-3
211-3
21
211-1
220-1
23

FIG. 3

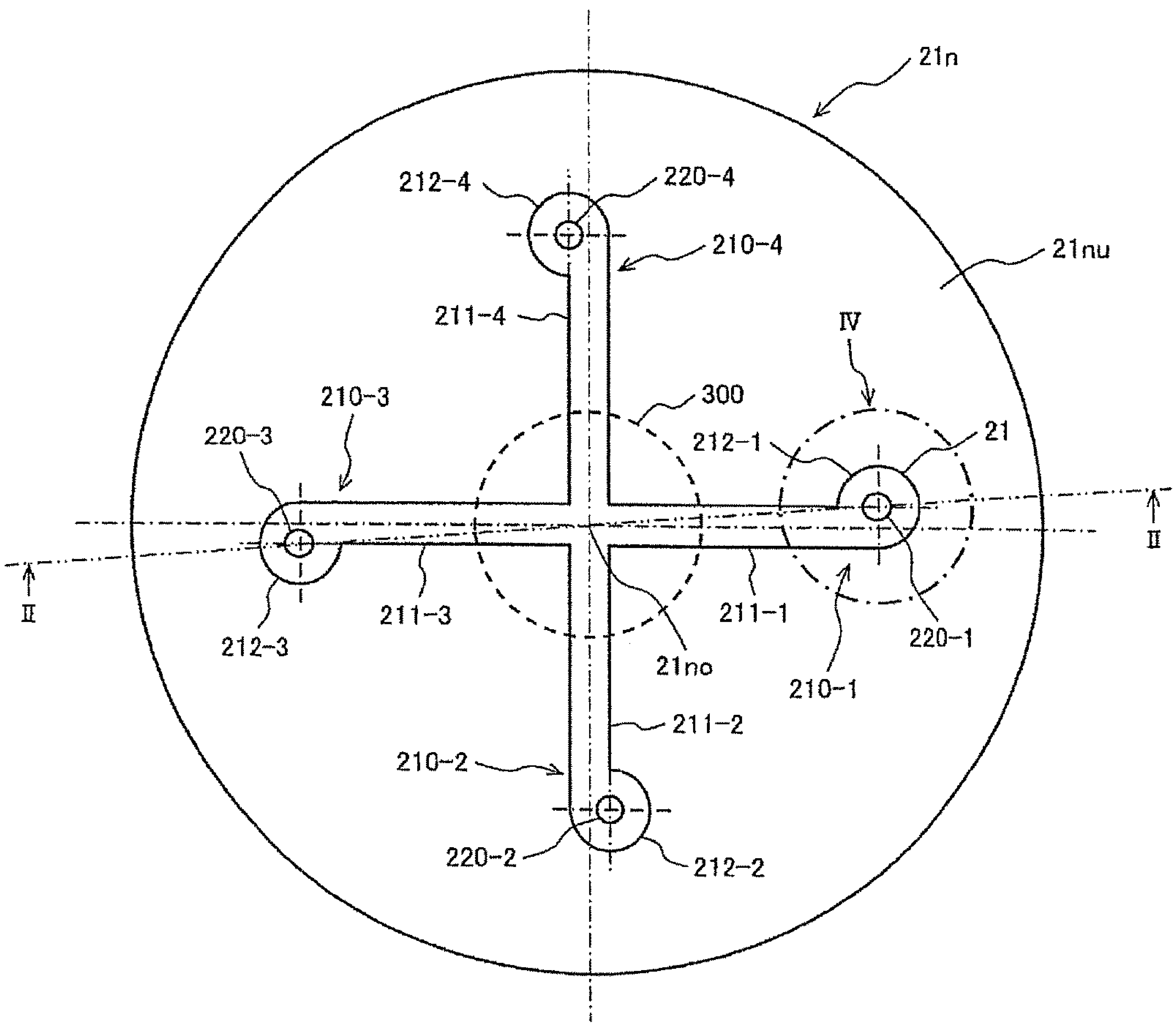
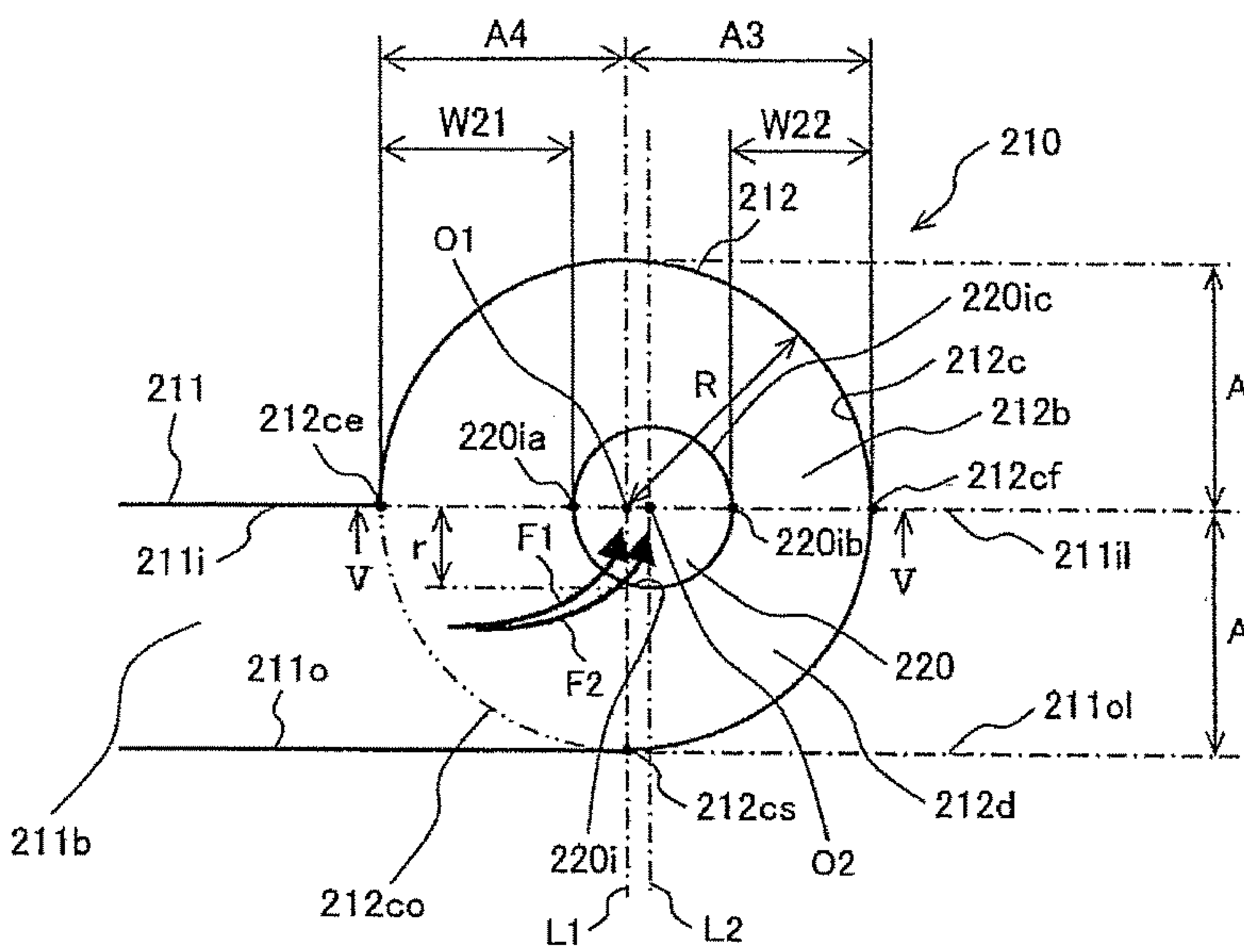

21n
212-4
220-4
210-4
21nu
211-4
IV
300
210-3
220-3
212-1
21
II
II
211-3
211-1
212-3
220-1
21no
210-1
211-2
210-2
220-2
212-2

FIG. 4


A4
A3
W21
W22
210
212
O1
220ic
212c
R
A2
211
212ce
220ia
212b
212cf
211i
V
r
F1
220ib
V
211il
A1
F2
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211o
211ol
211b
212co
220i
212cs
O2
212d
L1
L2

FIG. 5

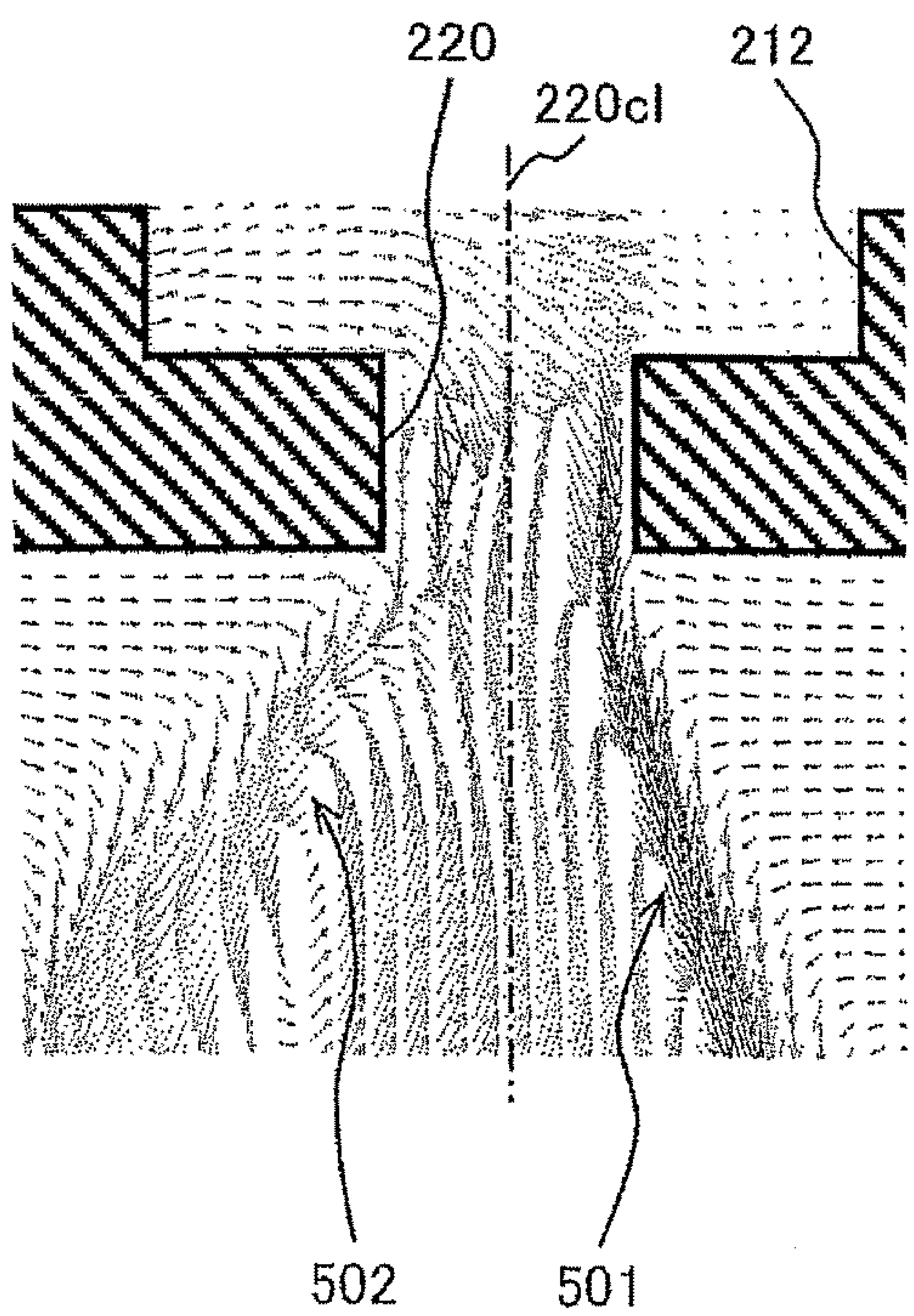

220
212
220cl
502
501

FIG. 6

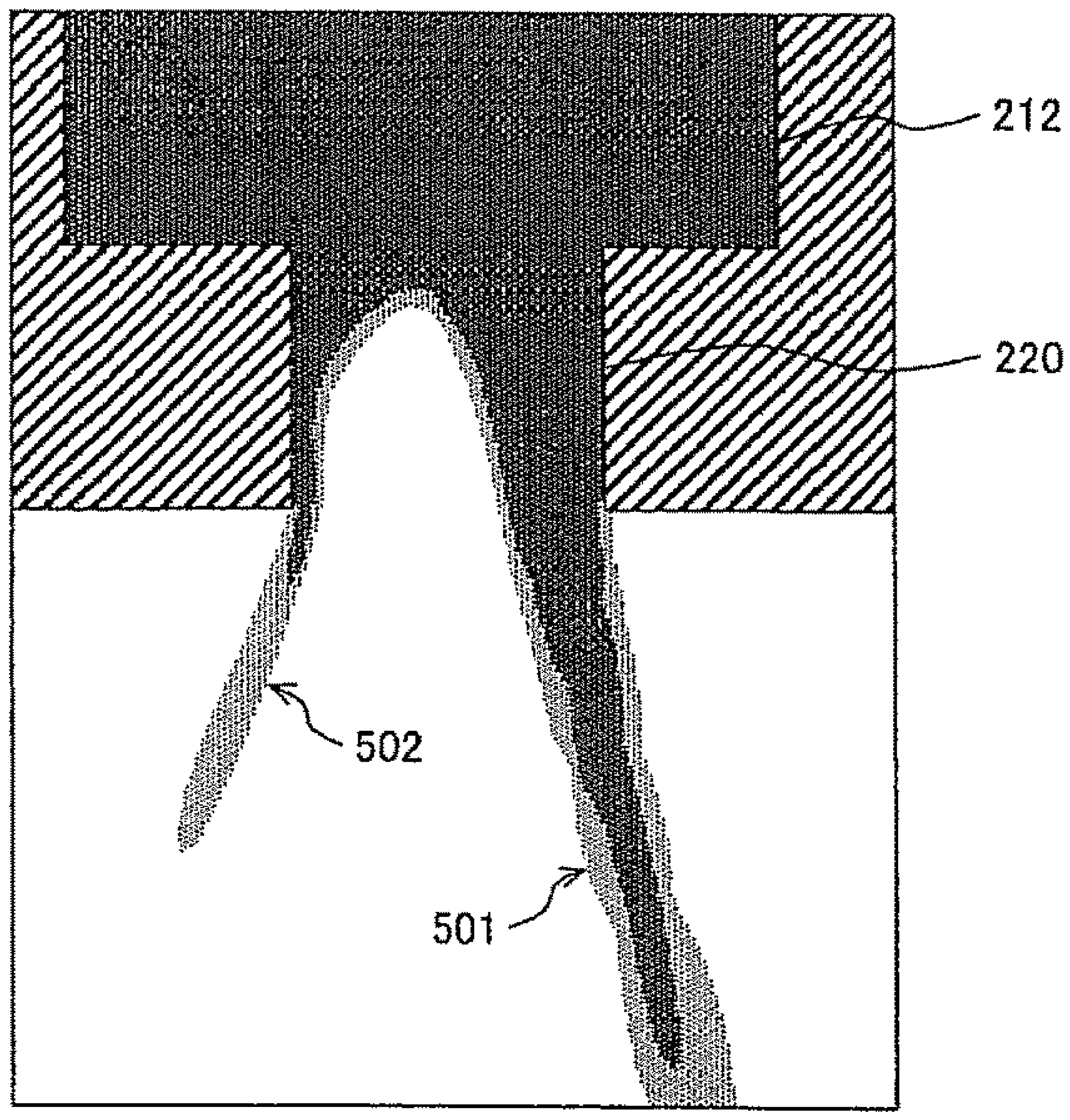


FIG. 7

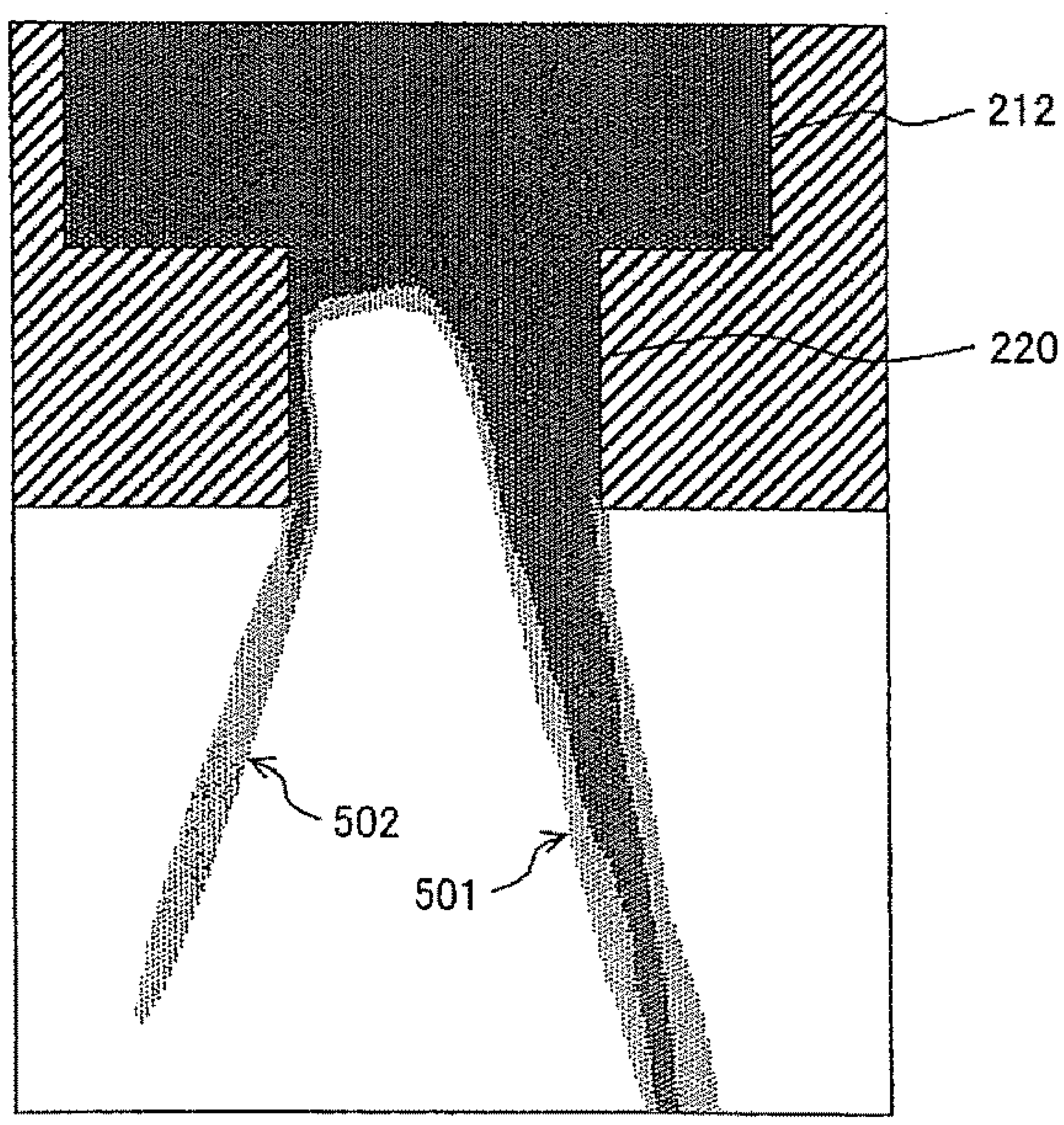


FIG. 8

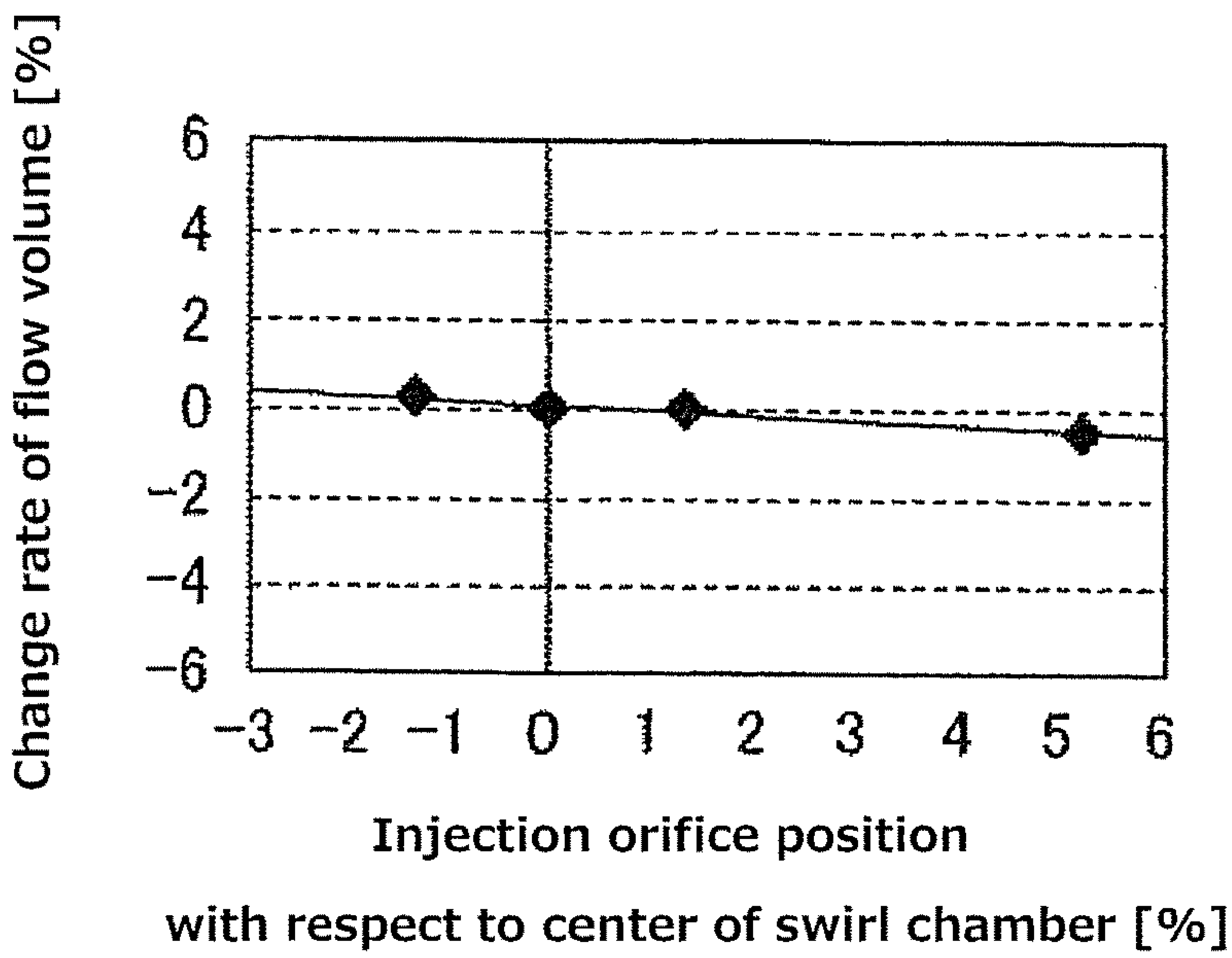

Change rate of flow volume [%]
6
4
2
0
-2
-4
-6
-3 -2 -1 0 1 2 3 4 5 6
Injection orifice position
with respect to center of swirl chamber [%]

FIG. 9

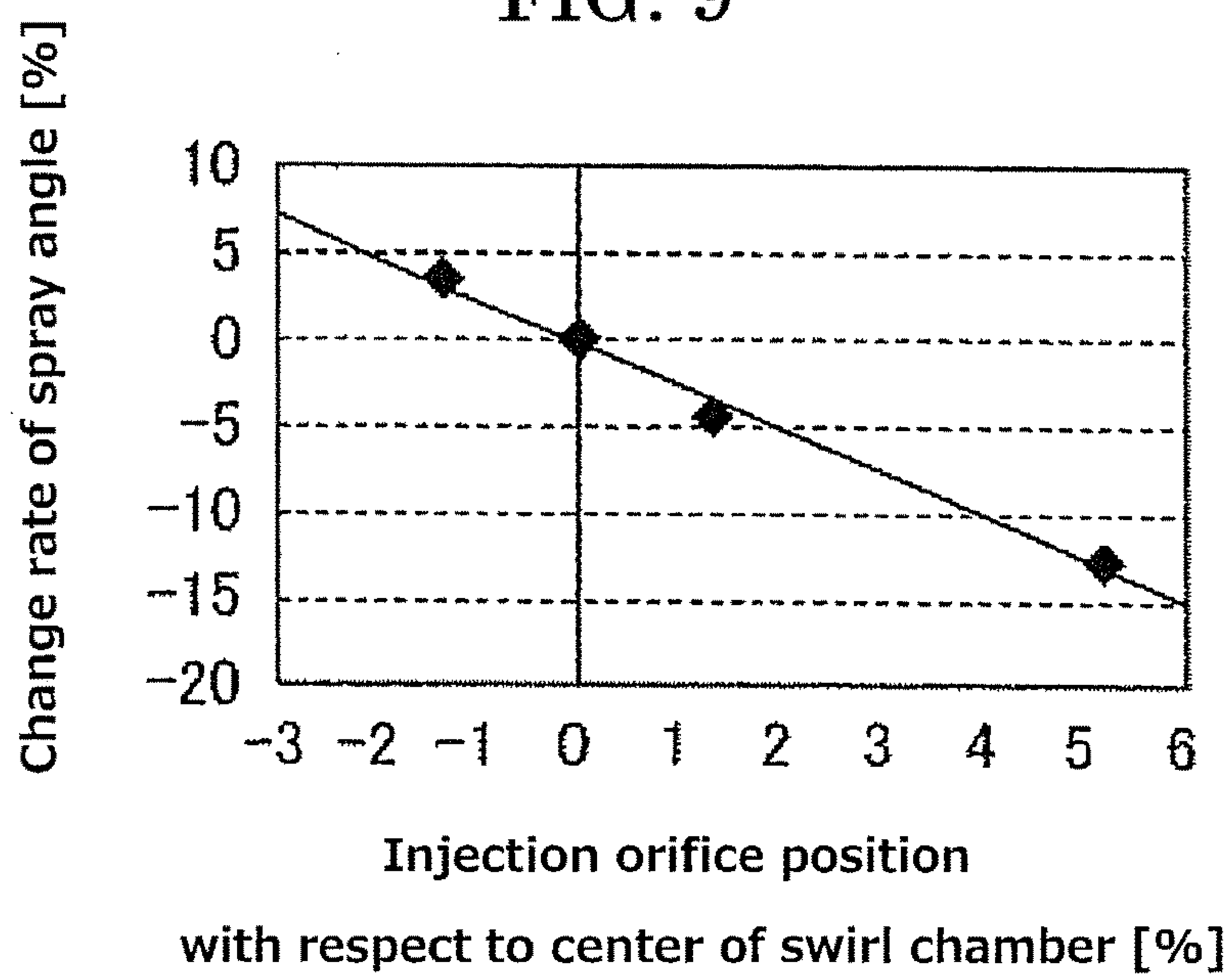

Change rate of spray angle [%]
10
5
0
-5
-10
-15
-20
-3 -2 -1 0 1 2 3 4 5 6
Injection orifice position
with respect to center of swirl chamber [%]

FIG. 10

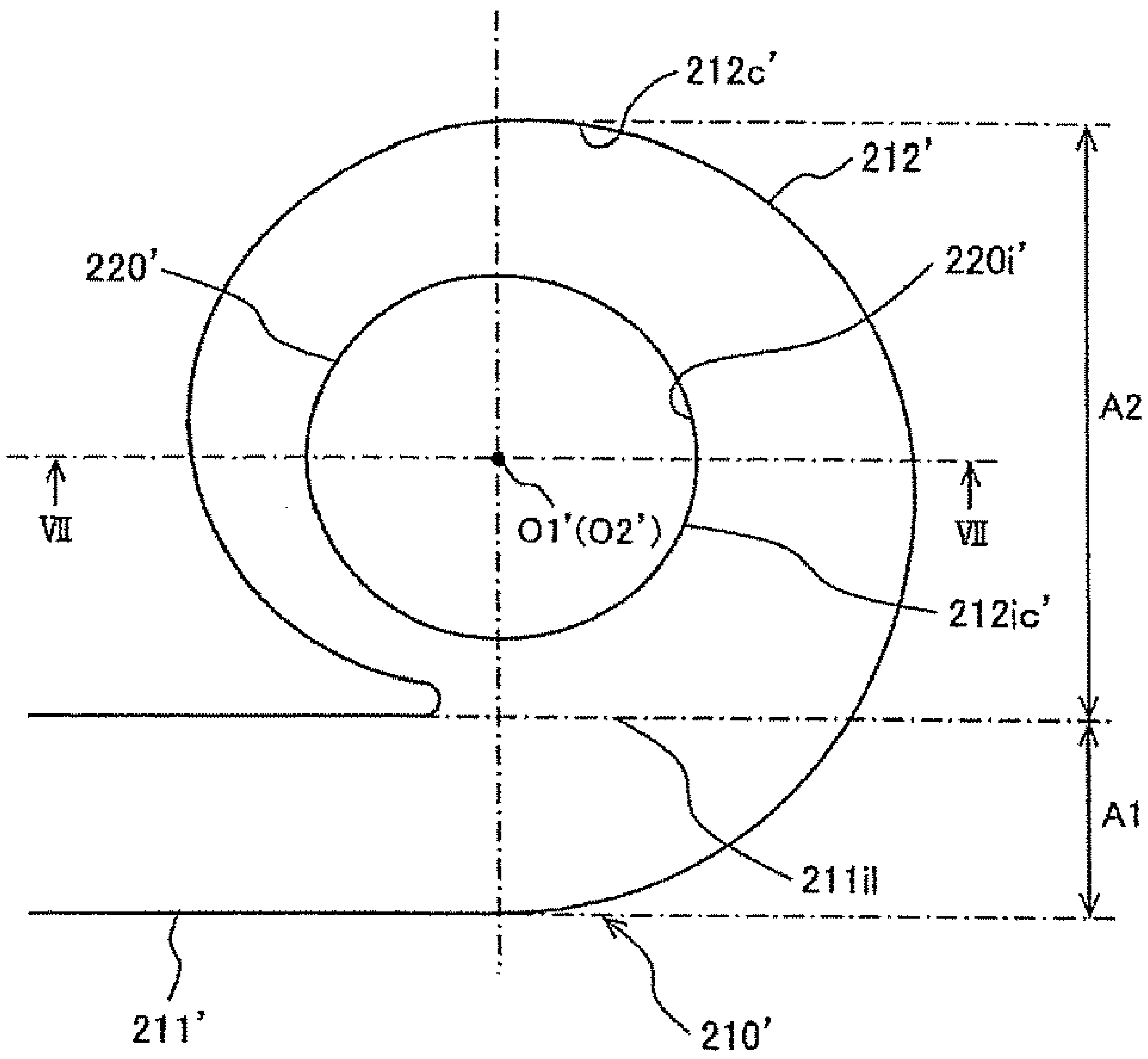

212c'
212'
220'
220i'
A2
VII
O1'(O2')
VII
212ic'
A1
211il
211'
210'

FIG. 11

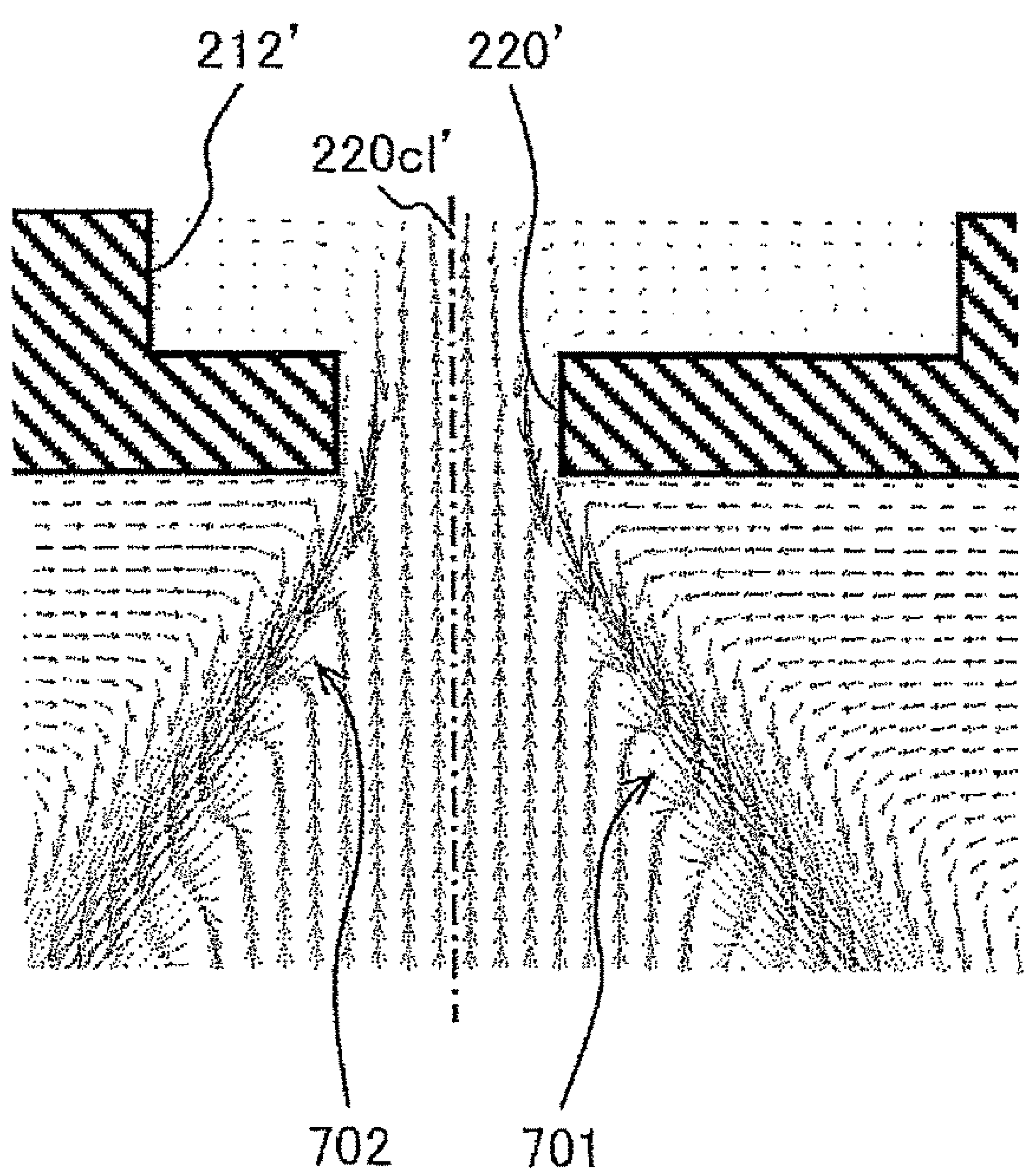
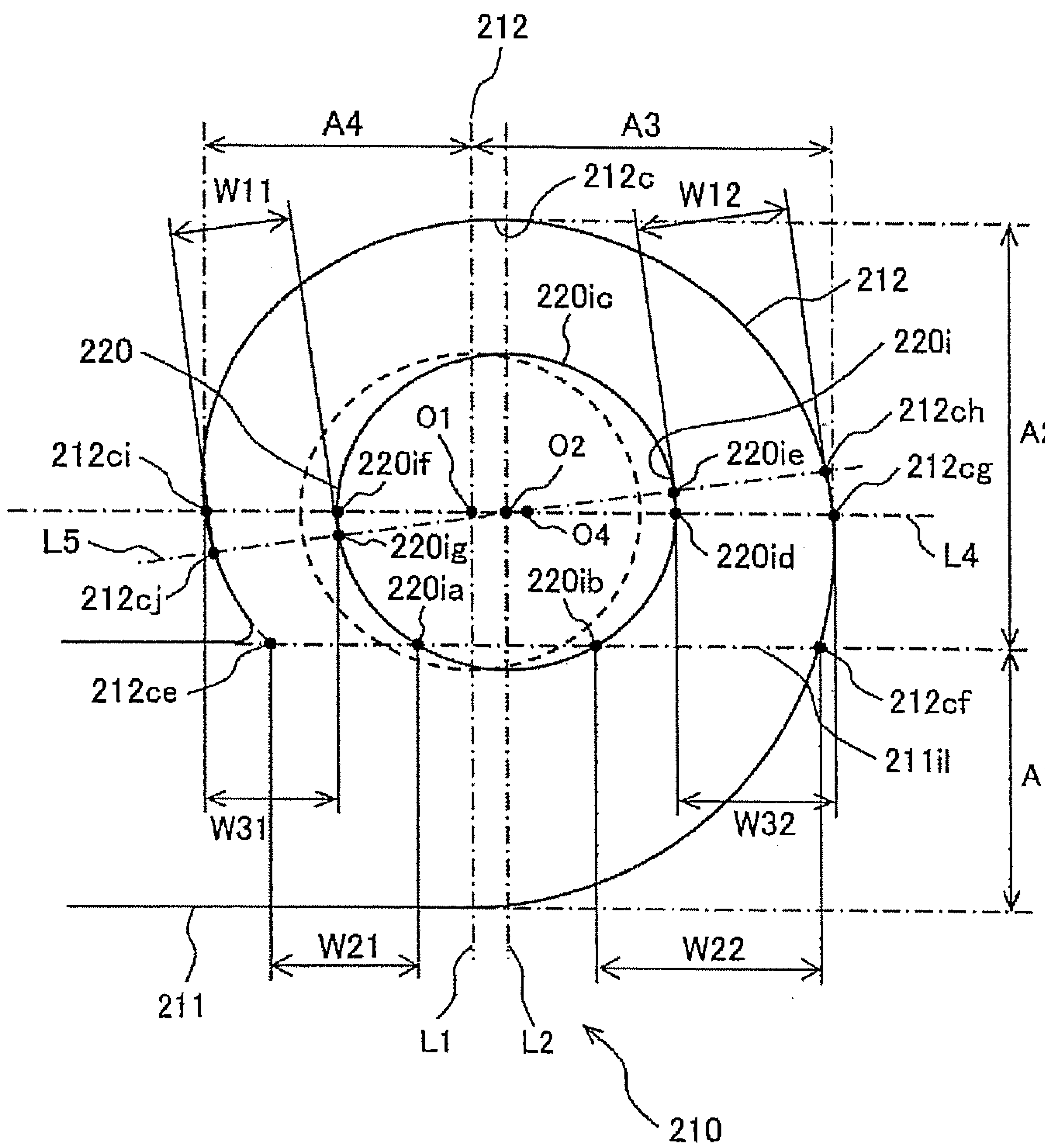

212'
220'
220cl'
702
701

FIG. 12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W12
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220ic
220
220i
212ch
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O1
O2
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220ie
212cg
L5
220ig
O4
220id
L4
212cj
220ia
220ib
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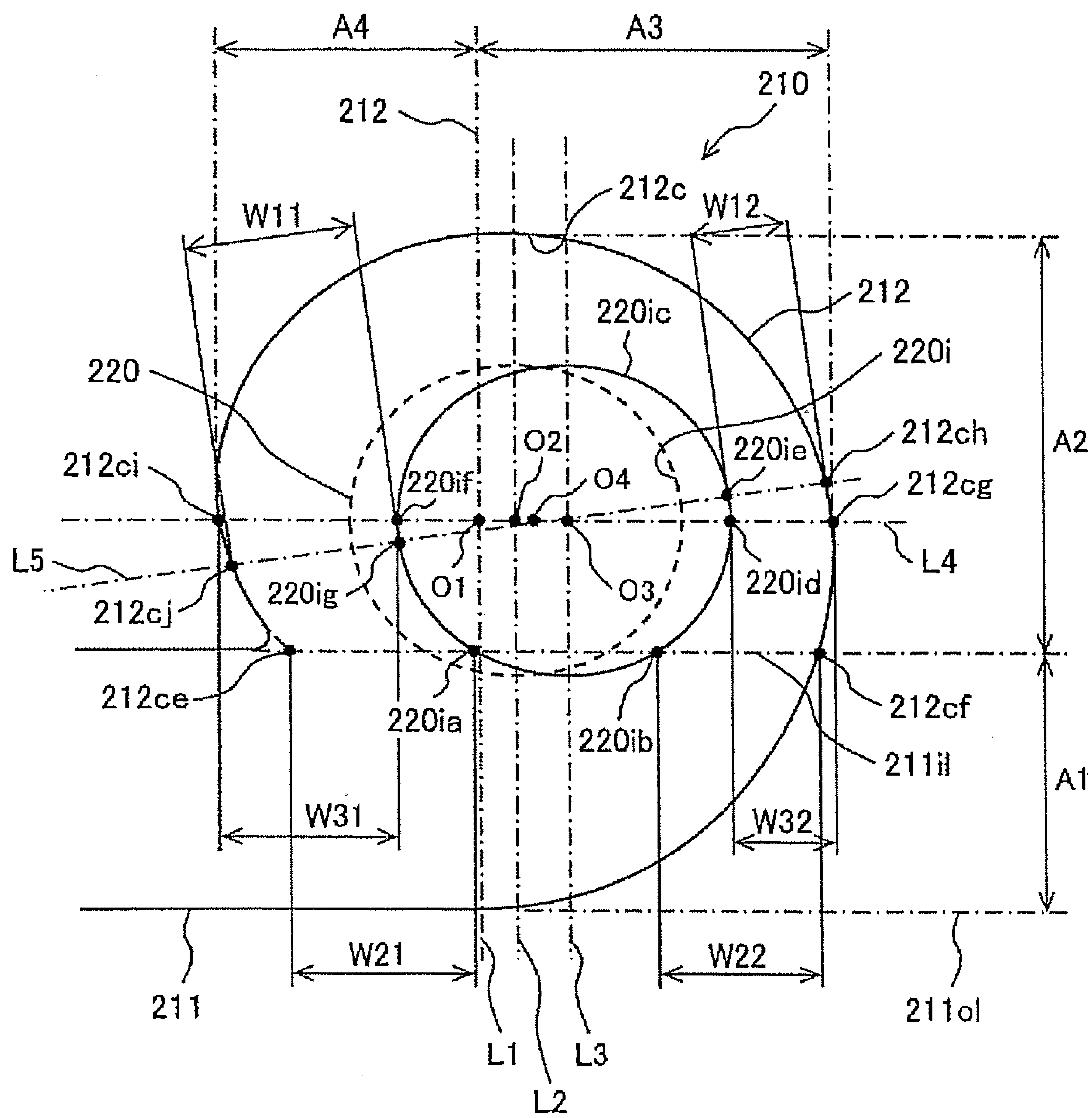
212cf
211il
A1
W31
W32
W21
W22
211
L1
L2
210

FIG. 13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A3
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220
212ch
A2
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O2
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220if
O4
L5
L4
220ig
O1
O3
220id
212cj
212ce
212cf
220ia
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A1
W31
W32
W21
W22
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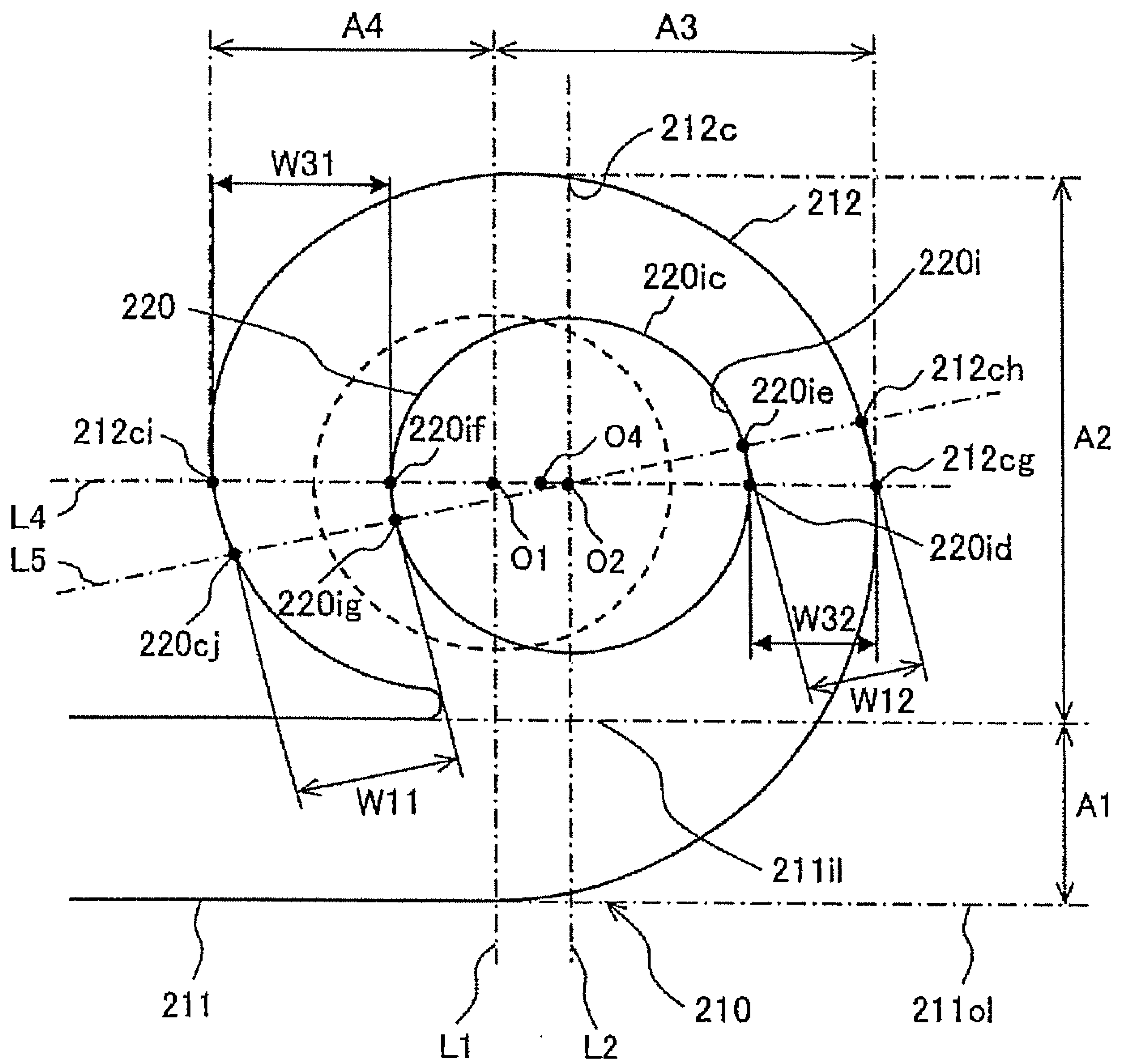
211ol
L1
L3
L2

FIG. 14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212ci
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212cg
A2
L4
L5
O1
O2
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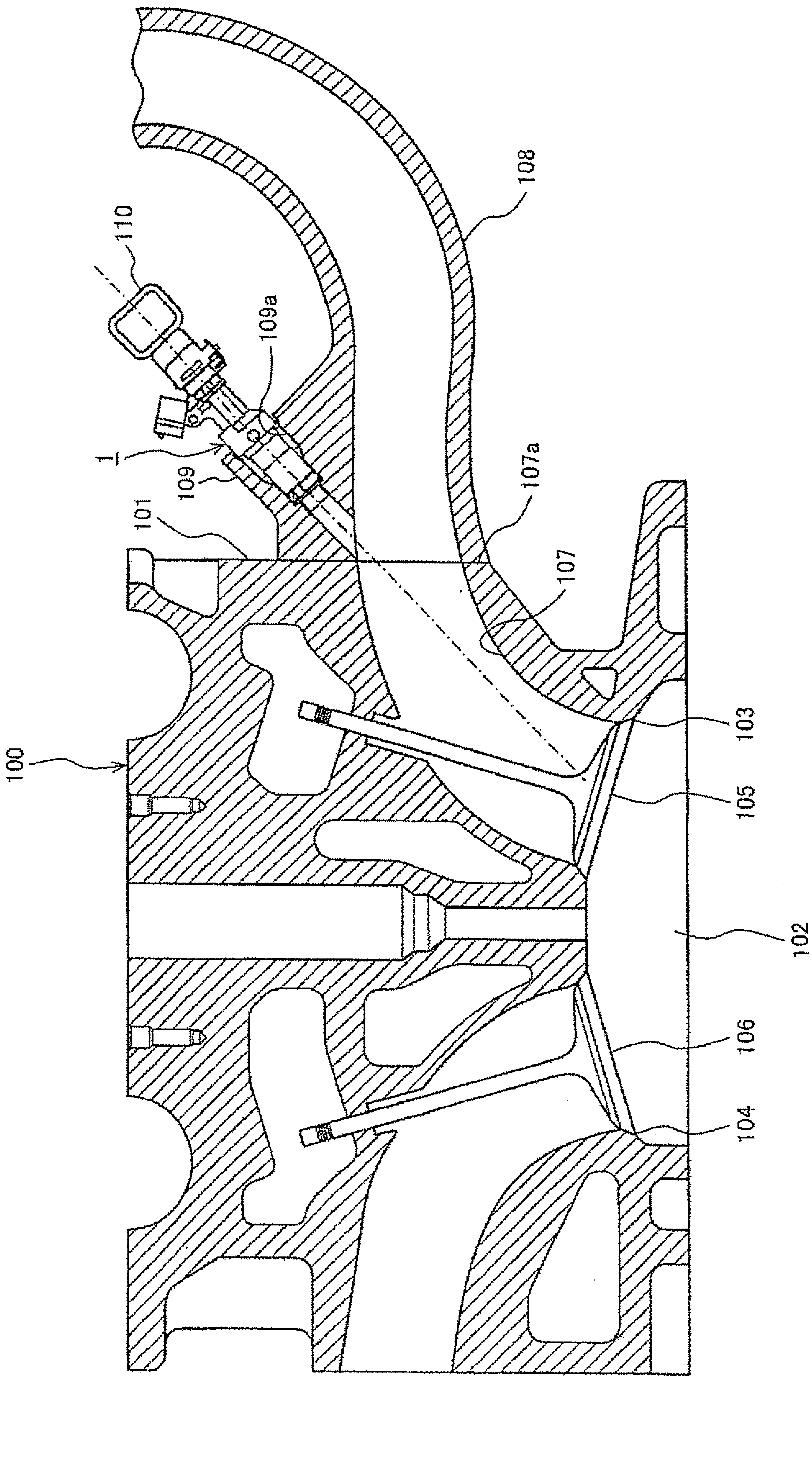
220ig
W32
220cj
W12
W11
A1
211il
211
L1
L2
210
211ol

FIG. 15



FUEL INJECTION VALVE

TECHNICAL FIELD

The present invention relates to a fuel injection valve that generates swirl fuel at an upstream side of a fuel injection orifice and injects the swirl fuel from the fuel injection orifice.

BACKGROUND ART

As a background art of the technical field relating to the present invention, a fuel injection valve disclosed in Japanese Patent Provisional Publication No. 2003-336562 (Patent Document 1) is known. This fuel injection valve has a valve seat member; a transverse passage that communicates with a downstream end of the valve seat; and a swirl chamber in which a downstream end of the transverse passage opens in a tangential direction. Furthermore, the transverse passage and the swirl chamber are provided between the valve seat member and an injector plate coupled to a front end surface of the valve seat member. The injector plate has each of fuel injection orifices which jets fuel having gotten a swirl in the swirl chamber. In the fuel injection valve, the fuel injection orifice is offset by a predetermined distance from a center of the swirl chamber toward an upstream end side of the transverse passage (see abstract). With this structure, atomization of the injected fuel is promoted, and a fuel injection response is improved.

However, in the fuel injection valve for jetting a fuel wherein the transverse passage, the swirl chamber, and the fuel injection orifice are formed on the injector plate, generally a spray angle is set by adjusting a diameter and length of the fuel injection orifice and a size (diameter) of the swirl chamber. If any one of the diameter and length of the fuel injection orifice or the size (diameter) of the swirl chamber is changed in order to adjust the spry angle, an amount of fuel jetted from the fuel injection orifice (fuel injection amount) is changed. Therefore, a long times have been spent on determining the diameter and length of the fuel injection orifice and the size (diameter) of the swirl chamber so that both of the fuel injection amount and the spray angle are kept within the predetermined range.

PRIOR ART DOCUMENT

Patent Document

Patent Document 1: Japanese Patent Provisional Publication No. 2003-336562

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a fuel injection valve in which a fuel injection amount and a spray angle can be adjusted easily.

In order to achieve the above object, according to one aspect of the present invention, a fuel injection valve comprises:

a valve body;

a fuel injection orifice provided in a downstream side of a valve seat which the valve body moves toward and away from;

a swirl chamber having a bottom surface on which an entry opening of the fuel injection orifice opens and an inner circumferential wall surrounding the bottom surface, the swirl chamber having:

a swirl passage for a fuel, the swirl passage formed between the inner circumferential wall and the entry opening; and

a transverse passage whose downstream end is opened in the inner circumferential wall of the swirl chamber in order to provide the fuel into the swirl chamber, the transverse passage having:

one width direction end part connected to an upstream side of the inner circumferential wall in a flow direction of a swirl fuel; and

the other width direction end part connected to a downstream side of the inner circumferential wall in the flow direction of the swirl fuel, and

when imaging an extension line formed by extending the other width direction end part of the transverse passage to a swirl chamber side, and a straight line segment passing a center of the swirl chamber and being perpendicular to the extension line,

a center of the entry opening of the fuel injection orifice being positioned to be shifted from the center of the swirl chamber along the extension line, and in two areas formed by dividing the swirl chamber into two with the straight line segment, the center of the entry opening of the fuel injection orifice being arranged in an area opposite to an area to which the transverse passage is connected.

According to another aspect of the invention, a fuel injection valve comprises:

a valve body;

a fuel injection orifice provided in a downstream side of a valve seat which the valve body moves toward and away from;

a swirl chamber having an entry opening of the fuel injection orifice and a swirl passage for a fuel, the swirl passage formed around the entry opening;

a transverse passage to provide the fuel into the swirl chamber; and

a nozzle plate on which the fuel injection orifice, the swirl chamber, and the transverse passage are formed,

wherein:

in flow passage width which is formed in both side of the entry opening on a line segment passing a center of the entry opening of the fuel injection orifice and a center of the nozzle plate, the flow passage width in the upstream side in the flow direction of the swirl fuel is smaller than the flow passage width in the downstream side in the flow direction of the swirl fuel.

Furthermore, according to another aspect of the invention, a fuel injection valve comprises:

a valve body;

a fuel injection orifice provided in a downstream side of a valve seat which the valve body moves toward and away from;

a swirl chamber having an entry opening of the fuel injection orifice and a swirl passage for a fuel, the swirl passage formed around the entry opening; and

a transverse passage to provide the fuel into the swirl chamber,

wherein:

a center of the entry opening of the fuel injection orifice is arranged to be shifted from a first position to a second position,

the first position being a position where a velocity component in a swirl direction of a fuel flowing into the fuel injection orifice is max, the second position being a position where the velocity component in the swirl direction gets small and where a velocity component in a center axis direction of the fuel injection orifice gets large.

According to the present invention, it is possible to largely change the spray angle while reducing a change rate of the fuel injection amount. Therefore, it is possible to provide a fuel injection valve being capable of providing a desired fuel injection amount and spray angle by easily adjusting the fuel injection amount and the spray angle. Thereby, design or design change of the fuel injection valve is simplified.

BRIEF EXPLANATION OF THE DRAWINGS

FIG. **1** is a longitudinal section drawing showing a cross section taken along a valve axis (a center axis line) of the fuel injection valve, according to the present invention.

FIG. **2** is a longitudinal section drawing enlargedly showing a vicinity (a nozzle part) of a valve part and a fuel injection part of the fuel injection valve shown in FIG. **1** (corresponding to a cross section taken along a line II-II in FIG. **3**).

FIG. **3** is a plan view of the nozzle plate viewed from a line III-III in FIG. **1**.

FIG. **4** is a plan view enlargedly showing a swirl chamber and a fuel injection orifice (an enlarged plan view of IV area in FIG. **3**).

FIG. **5** is a drawing showing an analytical result of a fuel flow at a cross section taken along a line V-V in FIG. **4**.

FIG. **6** is a longitudinal section drawing (a cross section taken along a V-V line in FIG. **4**) showing a fuel liquid film distribution in an inside of the fuel injection orifice and a vicinity thereof, when arranging an entry opening of the fuel injection orifice in a center of the swirl chamber.

FIG. **7** is a longitudinal section drawing (a cross section taken along a V-V line in FIG. **4**) showing a fuel liquid film distribution in an inside of the fuel injection orifice and a vicinity thereof, when arranging an entry opening to be shifted to area A**3** side from the center of the swirl chamber.

FIG. **8** is a drawing showing an analytical result of a change rate of flow volume in the embodiment of the present invention, when a position of the entry opening of the fuel injection orifice is changed.

FIG. **9** is a drawing showing an analytical result of a change rate of spray angle in the embodiment of the present invention, when a position of the entry opening of the fuel injection orifice is changed.

FIG. **10** is a plan view showing a configuration of a transverse passage, a swirl chamber, and a fuel injection orifice in a comparative example.

FIG. **11** is a drawing showing an analytical result of a fuel flow at a cross section taken along a line VII-VII in FIG. **10**.

FIG. **12** is a plan view enlargedly showing a swirl chamber and a fuel injection orifice in an example where a shape of the swirl chamber is modified (the enlarged plan view of IV area in FIG. **3**).

FIG. **13** is a plan view showing an example where a position of the fuel injection valve with respect to the swirl chamber is changed in the modified example of FIG. **12**.

FIG. **14** is a plan view enlargedly showing the swirl chamber and the fuel injection orifice in the example where the shape of the swirl chamber is further modified (the enlarged plan view of IV area in FIG. **3**).

FIG. **15** is a cross section of an internal combustion engine in which the fuel injection valve is mounted.

DESCRIPTION OF THE EMBODIMENTS

An embodiment of the present invention will be explained below with reference to FIGS. **1** to **8**.

A whole configuration of a fuel injection valve **1** will be explained using FIG. **1**. FIG. **1** is a longitudinal section drawing showing a cross section taken along a center axis line **1***a* of the fuel injection valve **1**, according to the present embodiment. The center axis line **1***a* coincides with an axis (valve axis) of a movable element **27** to which an after-mentioned valve body **17** is integrally fixed. The center axis line **1***a* also coincides with a center axis line of an after-mentioned cylindrical body **5**, and further coincides with each center line of an after-mentioned valve seat **15***b* and a nozzle plate **21***n*.

The fuel injection valve **1** is provided with the metal-made cylindrical body **5** extending from an upper end portion to a lower end portion of the fuel injection valve **1**. A fuel flow passage **3** is formed inside the cylindrical body **5** so as to extend substantially along the center axis line **1***a*. In FIG. **1**, the upper end portion (an upper end side) is called a base end portion (a base end side), and the lower end portion (a lower end side) is called a top end portion (a top end side). These terms “base end portion (base end side)” and “top end portion (top end side)” are based on a flow direction of fuel or a fixing structure to a fuel pipe (not shown). That is, the base end portion is an upstream side in the fuel flow direction, and the top end portion is a downstream side in the fuel flow direction. Furthermore, in the present description, for convenience of explanation, upper and lower positions of each element or component are defined based on FIG. **1**, and these upper and lower positions have nothing to do with up and down directions in a mounting state of the fuel injection valve **1** in an internal combustion engine.

The cylindrical body **5** is provided, at a base end portion thereof, with a fuel supply port **2**. A fuel filter **13** is fixed to the fuel supply port **2**. The fuel filter **13** is a member to filter out foreign particles included in the fuel.

The cylindrical body **5** is further provided, at the base end portion thereof, with an O-ring **11**. The O-ring **11** functions as a sealing member when the fuel injection valve **1** is connected to the fuel pipe.

At a top end portion of the cylindrical body **5**, a valve part **7** formed by the valve body **17** and a valve seat member **15** is formed. The valve seat member **15** has a step-shaped valve body accommodating hole **15***a* to accommodate the valve body **17**. A conical surface is formed at a certain position inside the valve body accommodating hole **15***a*, and the valve seat (seal part) **15***b* is formed on this cone-shaped surface. A guide surface **15***c* to guide movement of the valve body **17** in a direction along the center axis line **1***a* is formed at an upstream side (a base end side) with respect to the valve seat **15***b* in the valve body accommodating hole **15***a*. In conjunction with the valve seat **15***b* and the valve body **17**, a fuel passage is opened and closed. More specifically, when the valve body **17** is seated on the valve seat **15***b*, the fuel passage is closed, and when the valve body **17** separates from the valve seat **15***b*, the fuel passage is opened.

The valve seat member **15** is inserted to a top end inner side of the cylindrical body **5**, and is fixed to the cylindrical body **5** by laser welding. The laser welding **19** is performed throughout an entire circumference of the cylindrical body **5** from an outer circumferential side of the cylindrical body **5**. The valve body accommodating hole **15***a* penetrates the valve seat member in the direction along the center axis line **1***a*. A nozzle plate **21***n* is fixed to a lower end surface (a top end surface) of the valve seat member **15**. The nozzle plate **21***n* closes an opening of the valve seat member **15** which is formed by the valve body accommodating hole **15***a*.

In the present embodiment, a fuel injection part **21** that jets swirl fuel is formed by the valve seat member **15** and the nozzle plate **21***n*. The nozzle plate **21***n* is fixed to the valve seat member **15** by laser welding. The laser welding portion **23** is performed throughout a circumference of an injection orifice providing area where fuel injection orifices **220-1**, **220-2**, **220-3** and **220-4** (see FIG. **3**) are formed, so as to surround the injection orifice providing area. The valve seat member **15** can be fixed to the cylindrical body **5** by laser welding after being inserted and press-fitted to the top end inner side of the cylindrical body **5**.

In the present embodiment, as the valve body **17**, a ball valve having a spherical shape is used. Therefore, a plurality of cutting surfaces **17***a* are formed at some intervals in a circumferential direction of the valve body **17** at a portion facing the guide surface **15***c* of the valve seat member **15**. These cutting surfaces **17***a* give clearances between an inner circumferential surface of the valve seat member **15** and the valve body **17**, and the fuel passage is formed by these clearances. Here, the valve body **17** can be formed by an element other than the ball valve. For instance, a needle valve can be used.

In the present embodiment, the valve part **7** including the valve seat member **15** and the valve body **17**, and the nozzle plate **21***n* form a nozzle part to jet the fuel. The nozzle plate **21***n* where after-mentioned fuel injection orifice **220** and swirl passage **210** (a transverse passage **211** and a swirl chamber **212**) are formed is fixed to a top end surface of a nozzle part body (valve seat member **15**) having the valve part **7**.

A driving part **9** to drive the valve body **17** is disposed at a middle part of the cylindrical body **5**. The driving part **9** is formed by an electromagnetic actuator. More specifically, the driving part **9** is formed by a fixed core **25**, the movable element (a movable member) **27**, an electromagnetic coil **29**, and a yoke **33**.

The fixed core **25** is made of magnetic metal material, and is press-fixed to an inside at the longitudinal direction middle part of the cylindrical body **5**. The fixed core **25** is cylindrical in shape, and has a penetration hole **25***a* that penetrates the middle of the fixed core **25** in the direction along the center axis line **1***a*. The fixed core **25** can be fixed to the cylindrical body **5** by welding, or can be fixed to the cylindrical body **5** by press-fitting and the welding.

The movable element **27** is disposed at a top end side with respect to the fixed core **25** in the cylindrical body **5**. A movable core **27***a* is provided at a base end side of the movable element **27**. The movable core **27***a* faces the fixed core **25** through a slight gap δ. The movable element **27** is provided, at a top end side thereof, with a small diameter part **27***b*, and the valve body **17** is fixed to a top end of this small diameter part **27***b* by welding. In the present embodiment, the movable core **27***a* and the small diameter part **27***b* are integrally formed (as an integral member made of the same material). However, these two elements can be separately provided and fixed together. The movable element **27** has the valve body **17**, and moves the valve body **17** in a valve open/closure direction. The valve body **17** touches (is seated on) the valve seat member **15**, and also an outer circumferential surface of the movable core **27***a* touches an inner circumferential surface of the cylindrical body **5**, thereby supporting and guiding movement in the direction along the center axis line **1***a* (in the valve open/closure direction) of the movable element **27** at these two points in the valve axis direction.

The movable core **27***a* is provided, at an end surface thereof which faces the fixed core **25**, with a depressed portion **27***c*. A spring seat **27***e* of a spring (a coil spring) **39** is formed on a bottom surface of the depressed portion **27***c*. At an inner circumferential side of the spring seat **27***e*, a penetration hole **27***f* is formed so as to penetrate the small diameter part (the connecting part) **27***b* up to a top end side end portion of the small diameter part (the connecting part) **27***b* along the center axis line **1***a*. Furthermore, the small diameter part **27***b* is provided, at a side surface thereof, with an opening portion **27***d*. The penetration hole **27***f* opens to a bottom surface of the depressed portion **27***c*, and also the opening portion **27***d* opens to an outer circumferential surface of the small diameter part **27***b*, thereby forming the fuel flow passage **3** that communicates with the fuel passage **3** formed at the fixed core **25** and the valve part **7**.

The electromagnetic coil **29** is inserted or fitted onto an outer circumference of the cylindrical body **5** in a position in which the fixed core **25** and the movable core **27***a* face each other through the slight gap δ. The electromagnetic coil **29** is wound around a tubular bobbin **31** that is made of resin material, and then is inserted or fitted onto the outer circumference of the cylindrical body **5**. The electromagnetic coil **29** is electrically connected, through a wiring member **45**, to a connector pin **43** that is provided at a connector **41**. A driving circuit (not shown) is connected to the connector **41**, and a driving current flows to the electromagnetic coil **29** through the connector pin **43** and the wiring member **45**.

The yoke **33** is made of magnetic metal material. The yoke **33** is disposed at an outer circumferential side of the electromagnetic coil **29** so as to encircle the electromagnetic coil **29**, and serves as a housing of the fuel injection valve **1**. Furthermore, a lower end portion of the yoke **33** faces the outer circumferential surface of the movable core **27***a* through the cylindrical body **5**, then in cooperation with the movable core **27***a* and the fixed core **25**, the yoke **33** forms a closed magnetic path where magnetic flux generated by current supply to the electromagnetic coil **29** flows.

The coil spring **39** is set in a compressed state from the penetration hole **25***a* of the fixed core **25** to the depressed portion **27***c* of the movable element **27**. The coil spring **39** functions as a forcing member that forces the movable element **27** in a direction (in a valve closure direction) in which the valve body **17** touches (is seated on) the valve seat **15***b*. An adjuster (an adjusting element) **35** is disposed inside the penetration hole **25***a* of the fixed core **25**. A base end side end portion of the coil spring **39** touches a top end side end surface of the adjuster **35**. By adjusting a position of the adjuster **35** in the direction along the center axis line **1***a* in the penetration hole **25***a*, an urging force of the movable element **27** (i.e. the valve body **17**) by the coil spring **39** is adjusted.

The adjuster **35** has the fuel flow passage **3** that penetrates the middle of the adjuster **35** in the direction along the center axis line **1***a*. After the fuel flows in the fuel flow passage **3** of the adjuster **35**, the fuel flows to the fuel flow passage **3** of a top end side portion of the penetration hole **25***a* of the fixed core **25**, and then flows in the fuel flow passage **3** formed in the movable element **27**.

The cylindrical body **5** is provided, at the top end portion thereof, with an O-ring **46**. The O-ring **46** functions as a seal that air-tightly and liquid-tightly seals a gap between an inner circumferential surface of an insertion port **109***a* (see FIG. **15**) formed at the internal combustion engine side and an outer circumferential surface of the yoke **33** when the fuel injection valve **1** is mounted in the internal combustion engine.

The fuel injection valve **1** is molded and covered by a resin cover **47** from the middle up to an almost base end side end portion of the fuel injection valve **1**. A top end side end portion of the resin cover **47** covers a part of a base end side of the yoke **33**. Furthermore, the resin cover **47** also covers the wiring member **45**. The connector **41** is integrally formed with the resin cover **47**.

Next, working of the fuel injection valve **1** will be explained.

When the electromagnetic coil **29** is not energized (i.e. when the driving current does not flow in the electromagnetic coil **29**), the movable element **27** is forced in the valve closure direction by the coil spring **39**, and the valve body **17** touches (is seated on) the valve seat **15***b*. In this case, the gap δ is present between a top end side end surface of the fixed core **25** and the base end side end surface of the movable core **27***a*. Here, in the present embodiment, this gap δ corresponds to a stroke of the movable element **27** (i.e. a stroke of the valve body **17**).

When the electromagnetic coil **29** is energized and the driving current flows in the electromagnetic coil **29**, the magnetic flux is generated in the closed magnetic path formed by the movable core **27***a*, the fixed core **25**, and the yoke **33**. A magnetic attraction force is then generated between the fixed core **25** and the movable core **27***a*, which face each other through the gap δ, by the magnetic flux. When this magnetic attraction force exceeds a resultant force of the urging force by the coil spring **39** and a fuel pressure that exerts on the movable element **27** in the valve closure direction, the movable element **27** starts moving in the valve open direction. Then when the valve body **17** separates from the valve seat **15***b*, a clearance (a fuel flow passage) is formed between the valve body **17** and the valve seat **15***b*, and injection of the fuel is started. In the present embodiment, when the movable element **27** moves by a distance δ that is equal to the gap δ in the valve open direction and the movable core **27***a* touches the fixed core **25**, the movement in the valve open direction of the movable core **27***a* is stopped, and the movable core **27***a* is brought in a static valve open state.

When the driving current to the electromagnetic coil **29** is stopped, the magnetic attraction force diminishes, and then finally disappears. While the magnetic attraction force is diminishing, when the magnetic attraction force becomes smaller than the urging force of the coil spring **39**, the movable element **27** starts moving in the valve closure direction. Then when the valve body **17** touches and is seated on the valve seat **15***b*, the valve body **17** of the valve part **7** is brought in a static valve closure state.

Next, each configuration of the valve part **7** and the fuel injection part **21** will be explained with reference to FIGS. **2** and **3**. FIG. **2** is a longitudinal section drawing enlargedly showing a vicinity (a nozzle part) of a valve part **7** and a fuel injection part **21** of the fuel injection valve **1** shown in FIG. **1** (corresponding to a cross section taken along a line II-II in FIG. **3**). FIG. **3** is a plan view of the nozzle plate **21***n* viewed from a line III-III in FIG. **1**.

The top view of FIG. **3** is a top view of the nozzle plate **21***n* viewed from an entry side of the fuel injection orifice, and is a top view of an upper end surface **21***nu* side of the nozzle plate **21***n*. The upper end surface **21***nu* is a surface that faces a top end surface **15***t* of the valve seat member **15**. An end surface of the nozzle plate **21***n*, which is an opposite side to the upper end surface **21***nu*, is a lower end surface **21***nb*.

In the present embodiment, as shown in FIG. **2**, the nozzle plate **21***n* is formed by a plate member whose both end surfaces are flat, and the upper end surface **21***nu* and the lower end surface **21***nb* are parallel to each other. That is, the nozzle plate **21***n* is formed by a flat plate having a uniform thickness. Here, in the present embodiment, as shown in FIG. **3**, the fuel injection valve **1** is configured so that the center axis line **1***a* crosses the nozzle plate **21***n* at a center **21***no*.

The top end surface (a lower end surface) **15***t* of the valve seat member **15** is formed by a flat surface that is perpendicular to the center axis line **1***a*. The nozzle plate **21***n* is fixed to the top end surface **15***t* of the valve seat member **15**, and the top end surface **15***t* contacts or is contiguous to the upper end surface **21***nu* of the nozzle plate **21***n*.

As shown in FIG. **3**, on the nozzle plate **21***n*, transverse passages **211-1**, **211-2**, **211-3** and **211-4**, swirl chambers **212-1**, **212-2**, **212-3** and **212-4**, and fuel injection orifices **220-1**, **220-2**, **220-3** and **220-4** are formed. The transverse passages **211-1**, **211-2**, **211-3** and **211-4** and the swirl chambers **212-1**, **212-2**, **212-3** and **212-4** form swirl passages **210-1**, **210-2**, **210-3** and **210-4** to provide a swirl force to the fuel in the upstream side of the fuel infection orifice **220**. Four sets of swirl passages **210-1**, **210-2**, **210-3** and **210-4** and the fuel injection orifices **220-1**, **220-2**, **220-3** and **220-4** are formed in the same way as each other. Thus, in the following description, these are not distinguished, and these will be explained as the transverse passage **211**, the swirl chamber **212** and the fuel injection orifice **220**. However, in a case where structure or configuration of each set is changed, it will be explained as necessary.

As shown in FIG. **2**, the conical valve seat **15***b* whose diameter is reduced toward the downstream side is formed at the valve seat member **15**. A downstream end of the valve seat **15***b* is connected to a fuel introduction hole **300**. A downstream end of the fuel introduction hole **300** opens to the top end surface **15***t* of the valve seat member **15**. The fuel introduction hole **300** forms the fuel passage that introduces the fuel into the swirl passage **210**.

In order for the swirl passage **210** to receive supply of the fuel from the fuel introduction hole **300**, an upstream end portion of the transverse passage **211** is provided so as to face an opening surface of the fuel introduction hole **300**. In the present embodiment, as shown in FIG. **3**, the four transverse passages **211-1**, **211-2**, **211-3** and **211-4** are formed so that their upstream end portions communicate with each other. However, these four transverse passages **211-1**, **211-2**, **211-3** and **211-4** can be formed separately from each other.

In FIG. **2**, the transverse passage **211**, the swirl chamber **212** and the fuel injection orifice **220** are all formed on the nozzle plate **21***n* formed by one plate member. The nozzle plate **21***n* can be separated in a thickness direction, and be formed by a plurality of plates. For instance, the transverse passage **211** and the swirl chamber **212** are formed on one plate, and the fuel injection orifice **220** is formed on another plate. Then, by stacking or arranging these plates in layers, the nozzle plate **21***n* can be formed.

Furthermore, in the present embodiment, as shown in FIG. **2**, the fuel injection orifice **220** is formed parallel to the center axis line **1***a*. However, the fuel injection orifice **220** can be formed so as to have an inclination angle that is greater than 0° with respect to the center axis line **1***a*. By differentiating an inclination direction of each fuel injection orifice **220**, the fuel can be jetted in a plurality of directions.

In the present embodiment, as shown in FIG. **3**, the swirl passage **210-1** and the fuel injection orifice **220-1** form one fuel passage, the swirl passage **210-2** and the fuel injection orifice **220-2** form one fuel passage, the swirl passage **210-3** and the fuel injection orifice **220-3** form one fuel passage, and the swirl passage **210-4** and the fuel injection orifice

220-4 form one fuel passage. The swirl passage **210-1** is formed by the transverse passage **211-1** and the swirl chamber **212-1**, the swirl passage **210-2** is formed by the transverse passage **211-2** and the swirl chamber **212-2**, the swirl passage **210-3** is formed by the transverse passage **211-3** and the swirl chamber **212-3**, and the swirl passage **210-4** is formed by the transverse passage **211-4** and the swirl chamber **212-4**.

In the present embodiment, the four fuel passage sets, each of which is formed by the swirl passage **210** and the fuel injection orifice **220**, are provided on the nozzle plate **21***n*. Each of these four fuel passage sets is formed so as to extend radially from the center **21***no* side of the nozzle plate **21***n* toward an outer circumference of the nozzle plate **21***n*. That is, the transverse passage **211** is provided so as to extend radially from the center **21***no* side of the nozzle plate **21***n* toward the outer circumference of the nozzle plate **21***n* and is extended in a diameter direction of the nozzle plate **21***n*. Furthermore, the fuel passages are formed at angular intervals of 90° in a circumferential direction.

Regarding the number of the fuel passage sets, each of which is formed by the swirl passage **210** and the fuel injection orifice **220**, it is not limited to four and it can be two or three, or five or more. Furthermore, only one set of the swirl passage **210** and the fuel injection orifice **220** may be formed.

Here, a structural relationship between the swirl chamber **212** and the fuel injection orifice **220** will be explained in detail with reference to FIG. **4**. FIG. **4** is a plan view enlargedly showing a swirl chamber **212** and a fuel injection orifice **220** (an enlarged plan view of IV area in FIG. **3**).

The transverse passage **211** is connected to the swirl chamber **212** so as to be offset with respect to a center O1 of the swirl chamber **212**. One width direction end part (side wall) **211***o* of the transverse passage **211** is connected to an inner circumferential wall **212***c* which is positioned in an upstream side in a flow direction of the swirl fuel, and the other width direction end part (side wall) **211***i* is connected to the inner circumferential wall **212***c* which is positioned in an downstream side in the flow direction of the swirl fuel. Therefore, the inner circumferential wall (side wall) **212***c* of the swirl chamber **212** has an opening **212***co* at the connection part of the transverse passage **211**.

The inner circumferential wall **212***c* of the swirl chamber **212** is provided so as to form a circumference around the entry opening **220***i* of the fuel injection orifice **220** so that the fuel flowing into the swirl chamber **212** from the transverse passage **211** swirls. That is, a swirl flow passage **212***d* for the fuel is formed between the inner circumferential wall **212***c* of the swirl chamber **212** and the entry opening **220***i* of the fuel injection orifice **220**.

The transverse passage **211** has a rectangular in shape in cross section (transverse section) that is perpendicular to the extending direction of the transverse passage **211** or the fuel flow direction. Side walls (side surfaces) **211***o* and **211***i* and a bottom surface **211***b* of the transverse passage **211** are formed by the nozzle plate **21***n*. Furthermore, an upper surface (a ceiling surface) **211***u* (see FIG. **2**) of the transverse passage **211** is formed by the top end surface **15***t* of the valve seat member **15**.

The side wall **211***o* of the transverse passage **211** is connected to the swirl chamber **212** at an angle in contact with the inner circumferential wall **212***c* of the swirl chamber **212**. A downstream end of the side wall **211***o* is connected to a wall starting end portion **212***cs* of the inner circumferential wall **212***c* of the swirl chamber **212**.

Furthermore, the side wall **211***i* of the transverse passage **211** is connected to the swirl chamber **212** at an angle where it intersects the inner circumferential wall **212***c* of the swirl chamber **212**. Here, "intersect" means that the side wall **211***i* and its extension line are going across the inner circumferential wall **212***c*, and doesn't include a configuration that the side wall **211***i* and its extension line are in contact with the inner circumferential wall **212***c*. A downstream end of the side wall **211***i* is connected to a wall ending end portion **212***ce* of the inner circumferential wall **212***c* of the swirl chamber **212**.

The wall starting end portion **212***cs* of the inner circumferential wall **212***c* of the swirl chamber **212** is an end portion which is positioned in the upstream side in the swirl direction of the fuel. The wall ending end portion **212***ce* of the inner circumferential wall **212***c* is an end portion which is positioned in the downstream side in the swirl direction of the fuel. In the wall ending end portion **212***ce*, a chamfering portion such as an inclined or rounded portion is sometimes formed. In such a case, an intersection point where imaginary lines which are formed by respectively extending the inner circumferential wall **212***c* and the side wall **211***i* intersect each other should be defined as the wall ending end portion (downstream side end portion) **212***ce*.

In the present embodiment, the inner circumferential wall **212***c* from the wall starting end portion **212***cs* of the swirl chamber **212** to the wall ending end portion **212***ce* is formed so as to be an arc shape in which radius R from the center O1 of the swirl chamber **212** is constant. That is, the inner circumferential wall **212***c* is formed by a part of a circumference of a perfect circle. On the other hand, the entry opening **220***i* of the fuel injection orifice **220** has a circular shape having a radius r smaller than the radius R of the inner circumferential wall **212***c* of the swirl chamber **212**. With this structure, a bottom surface **212***b* of the swirl flow passage **212***d* is formed between the entry opening edge **220***ic* of the fuel injection orifice **220** and the inner circumferential wall **212***c* of the swirl chamber **212**. Furthermore, in case that a center axis line of the fuel injection orifice **220** inclines with respect to the bottom surface **212***b*, even if a transverse section of the fuel injection orifice **220** has a circular shape, the entry opening **220** is elliptic, not circular. Regardless of the presence/absence of inclining, the center axis line of the fuel injection orifice **220** passes through a center O2 of the entry opening **220***i*.

FIG. **4** is a plan view and a projection drawing where the fuel injection orifice **220**, the swirl chamber **212**, and the transverse passage **211** are projected to a plane surface (projection plane) vertical to the center axis line **1***a* of the fuel injection valve **1**. In FIG. **4**, an extension line **211***ol* (first extension line) of the side wall **211***o* of the transverse passage **211** and an extension line **211***il* (second extension line) of the side wall **211***i* are shown by projecting. The first extension line **211***ol* is an imaginary line extending along the side wall **211***o*. The second extension line **211***il* is an imaginary line extending along the side wall **211***i*.

The second extension line **211***il* divides the bottom surface of the swirl chamber **212** (bottom surface **212***b* of the swirl flow passage **212***d*) into two areas A1 and A2. The area A1 is an area which is located in the side wall **211***o* or its extension line **211***ol* side with respect to the second extension line **211***il*. The wall starting end portion **212***cs* of the inner circumferential wall **212***c* is in the area A1, and formed by a swirl flow passage part in the wall starting end portion **212***cs* side of the inner circumferential wall **212***c*. The area A2 is an area positioned in an opposite side to the side wall **211***o* or its extension line **211***ol* side with respect to the second extension line **211***il*. The area A**2** is formed by a swirl flow passage part in the wall ending end portion **212***ce* side of the inner circumferential wall **212***c*. Furthermore, it is defined that the areas A**1** and A**2** don't include the second extension line **211***il* itself.

A part of the entry opening edge **220***ic* of the fuel injection orifice **220** is arranged in the area A**1** side over the second extension line **211***il*. That is, a part of the entry opening **220***i* of the fuel injection valve **220** opens toward the area A**1** side.

In the present embodiment, the center O**2** of the entry opening **200***i* of the fuel injection orifice **220** is positioned on the second extension line **211***il*. Because of this, the entry opening **220***i* of the fuel injection orifice **220** is protruded toward the area A**1** side over the second extension line **211***il* by the radius r of the fuel injection orifice **220**. Therefore, the entry opening edge **220***ic* of the fuel injection orifice **220** intersects with the second extension line **220***il* at two points **220***ia* and **220***ib*. That is, the entry opening **220***i* of the fuel injection orifice **220** is arranged so that the second extension line **220***il* and the entry opening edge **220***ic* of the fuel injection orifice **220** are intersected at the two points **220***ia* and **220***ib*. Furthermore, a protrusive degree of the entry opening **220***i* toward the area A**1** side is not limited to the size of the radius r of the fuel injection orifice **220**. The protrusive degree may be bigger than the radius r and may be smaller than the radius r.

In the present embodiment, in addition, the center O**2** of the entry opening **200***i* of the fuel injection orifice **220** is arranged at a position which is shifted from the center O**1** of the swirl chamber **212** in a direction along the second extension line **211***il*. That is, the center O**2** of the entry opening **220***i* of the fuel injection orifice **220** is eccentric with respect to the center O**1** of the swirl chamber **212**.

Here, divisions of the swirl chamber **212**, which are different from the area A**1** and A**2**, will be explained. First, a line segment L**1**, which pass through the center O**1** of the swirl chamber **212** and is perpendicular to the second extension line **211***i*, is imaged. Next, the swirl chamber **212** is divided into two areas A**3** and A**4** by the line segment L**1**. The area A**3** is a division opposite to a side where the transverse passage **211** is connected with respect to the line segment L**1**. The area A**4** is a division in a side where the transverse passage **211** is connected with respect to the line segment L**1**. The area A**4** is formed of an uppermost upstream side section and a lowermost downstream side section of the swirl flow passage **212***d*. The area A**3** is formed of a middle flow passage section of the swirl flow passage **212***d*. Furthermore, it is defined that the areas A**3** and A**4** don't include the line segment L**1** itself.

A shifting direction of the center O**2** is a direction along the second extension line **211***il* and is in a side of an intersection point **212***cf* positioned in an opposite side to the wall ending end portion **212***ce* of the inner circumferential wall **212***c* across the entry opening **220***i* of the fuel injection orifice **220**. The intersection point **212***cf* is the intersection point of the second extension line **211***il* and the inner circumferential wall **212***c*.

In the present embodiment, as the center O**1** of the swirl chamber **212** and the center O**2** of the entry opening **220***i* are arranged on the second extension line **211***il*, the center O**2** of the entry opening **220***i* exists at a position which is shifted from the center O**1** of the swirl chamber **212** toward the intersection point **212***cf* on the second extension line **211***il*. Furthermore, on the second extension line **211***il*, the center O**2** of the entry opening **210***i* is arranged in the area A**3** near to the **212***cf* side than the center O**1**, which is a center point dividing a distance between the intersection point **212***cf* and the wall ending end portion **212***ce* into two equal parts.

However, the shifting direction of the center O**2** is not limited to the direction disclosed in the present embodiment, and may be disposed so that the center O**2** of the entry opening **220***i* is positioned in the area A**3**. In this case, a line segment (imaginary line segment) L**2**, which passes through the center O**2** of the entry opening **220***i* and is perpendicular to the second extension line **211***il*, doesn't overlap with the imaginary line segment L**1** and is parallel to the imaginary line segment L**1**. That is, there is a substantially distance between the imaginary line segment L**1** and the imaginary line segment L**2**, and they have a parallel relationship each other. Here, the term "there is a substantially distance" means that a case that the distance is zero is not included.

As compared with a case that the center O**2** of the entry opening **220***i* of the fuel injection orifice **220** corresponds to the center O**1** of the swirl chamber **212**, the center O**2** is arranged in the intersection point **212***cf* side. Therefore, in a flow passage width W**21** and a flow passage width W**22**, which are formed in both sides of the entry opening **220***i* in the direction of the second extension line **211***il*, the flow passage width W**22** is narrower than the flow passage width W**21**. The flow passage width W**21** corresponds to a distance between the wall ending end portion **212***ce*, which is an imaginary intersection point of the second extension line **211***il* and the inner circumferential wall **212***c*; and a first intersection point **220***ia* of the second extension line **211***il* and the entry opening edge **212***ic*. The flow passage width W**22** corresponds to a distance between a second intersection point **220***ib* of the second extension line **211***il* and the entry opening edge **212***ic*; and the intersection point **212***cf* of the second extension line **211***il* and the inner circumferential wall **212***c*, the intersection point **212***cf* being in the wall starting end portion **212***cs* side.

A fuel flow, which flows into the fuel injection orifice **220** from the swirl chamber **212** and is jetted from the fuel injection orifice **220**, will be explained with reference to FIG. **5**. FIG. **5** is a drawing showing an analytical result of a fuel flow at a cross section taken along a line V-V in FIG. **4**.

The fuel flow flowing into the swirl chamber **212** from the transverse passage **211** flows along the inner circumferential wall **212***c* of the swirl chamber **212**, and swirls around the entry opening **220***i* of the fuel injection orifice **220**. At this stage, the fuel is provided with the swirl force. The fuel flow provided with the swirl force flows into the fuel injection orifice **220** while swirling. The fuel jetted from the fuel injection orifice **220** forms a liquid film while keeping the swirl force, and further spreads as a droplet state. Atomized fuel spray is then formed.

In the present embodiment, the entry opening **220***i* of the fuel injection orifice **220** is formed so as to protrude toward the area A**1** side over the extension line **211***il* of the side wall **211***i*, so a part of fuel flowing into the swirl chamber **212** from the transverse passage **211** flows into the fuel injection orifice **220** without swirling in the swirl chamber **212**. That is, the fuel tends to flow into the fuel injection orifice **220**. A tendency of flowing into the fuel injection orifice **220** in a fuel flow can be adjusted by modifying a protruding degree toward the area A**1** side in the fuel injection orifice **220**. Thereby, a flow volume of a fuel flowing into the fuel injection orifice **220**, that is, injection amount can be adjusted. Generally, when the protruding degree toward the area A**1** side is increased, the flow volume of fuel flowing into the fuel injection orifice **220** (injection amount) is increased.

In FIG. **5**, as a shade of an arrow showing the fuel flow becomes darker, the flow velocity increases. In the present embodiment, in a **501** side where the fuel flows into the fuel injection orifice **220** without sufficiently swirling in the swirl chamber **212**, a fuel velocity in an axial direction of the fuel injection orifice **220** (axial direction velocity) is large, and a fuel spray with strong penetration force is formed. Furthermore, in the **501** side, a spray angle is small, and penetration is long. On the other hand, in a **502** side, a fuel flow which has gotten a swirl force by swirling in the swirl chamber **212** is jetted from the fuel injection orifice **220**. Therefore, as compared with in the **501** side, in the **502** side, an axial direction velocity of the fuel is small, and a fuel spray with weak penetration force is formed. Furthermore, as compared with in the **501** side, in the **502** side, the swirl force is strong, so the spray angle is large, and the penetration is short.

Furthermore, in the present embodiment, the center O**2** of the entry opening **220***i* of the fuel injection orifice **220** is shifted from the center O**1** of the swirl chamber **212** to be arranged in the area A**3** shown in FIG. **4**. That is, the center O**2** of the entry opening **220***i* of the fuel injection orifice **220** is arranged at a position shifted from the center O**1** of the swirl chamber **212** toward the intersection point **212***cf* side in a direction along the second extension line **211***il*. By adjusting a shift amount in the direction along the second extension line **211***il* from the center O**1** of the swirl chamber **212**, the spray angle of the fuel spray can be adjusted.

Furthermore, in a comparison between flow velocity of the fuel flow F**2** and flow velocity of the fuel flow F**1**, the flow velocity of the fuel flow F**2** is faster than the flow velocity of the fuel flow F**1**. The fuel flow F**1** is a flow that the fuel flowed into the swirl chamber **212** tries to flow into the fuel injection orifice **220** in further upstream side. The fuel flow F**2** is a flow that the fuel flowed into the swirl chamber **212** tries to flow into the fuel injection orifice **220** in further downstream side.

The fuel flow having a fast fuel velocity can be flowed into the fuel injection orifice **220** by shifting the center O**2** of the entry opening **220***i* of the fuel injection orifice **220** toward the area A**3** side with respect to the imaginary line segment L**1**. Because of this, rectilinearity of the fuel flow inside the fuel injection orifice **220** increases, and velocity component in a direction of a center axis line **220***c***1** of the fuel injection orifice **220** gets large. The rectilinearity of the fuel flow inside the fuel injection orifice **220** increases, and thereby the spray angle of the fuel spray jetted from the fuel injection orifice **220** can be narrow. Therefore, the present embodiment is available in case that not only adjustment of the spray angle in the fuel spray but also the fuel spray with a narrow spray angle is required.

Here, a fuel liquid film distribution formed in the fuel injection orifice in the present embodiment will be explained with reference to FIG. **6** and FIG. **7**. FIG. **6** is a longitudinal section drawing (a cross section taken along a V-V line in FIG. **4**) showing a fuel liquid film distribution in an inside of the fuel injection orifice and a vicinity thereof, when arranging an entry opening of the fuel injection orifice in a center of the swirl chamber. FIG. **7** is a longitudinal section drawing (a cross section taken along a V-V line in FIG. **4**) showing a fuel liquid film distribution in an inside of the fuel injection orifice and a vicinity thereof, when arranging an entry opening to be shifted to area A**3** side from the center of the swirl chamber. Furthermore, in FIG. **6** and FIG. **7**, a state of the liquid film is shown with two kinds of shade. A dark part is where a proportion of the fuel is 100%, and a pale part is where the proportion of the fuel is less than 100% because air is mixed therein.

In both of FIG. **6** and FIG. **7**, the fuel liquid film of the **501** side is thicker as compared with the fuel liquid film of the **502** side.

However, in comparison between FIG. **6** and FIG. **7**, it is found that the liquid film in the **502** side is very thin inside the fuel injection orifice **220** in FIG. **7**, with respect to FIG. **6**. Conversely, in the **501** side, the fuel flowing amount to the fuel injection orifice **220** increases, so the fuel liquid film gets thick. Furthermore, rectlinearity of the fuel flowing into the fuel injection orifice **220** increases, so the fuel spray travel gets long. The **501** side is located in the upstream side with respect to the **502** side in the swirl direction of the fuel.

Change rates of a fuel injection amount (flow volume) and spray angle in the present embodiment will be explained with reference to FIG. **8** and FIG. **9**. FIG. **8** is a drawing showing an analytical result of a change rate of flow volume in the present embodiment, when a position of the entry opening of the fuel injection orifice is changed. FIG. **9** is a drawing showing an analytical result of a change rate of spray angle in the present embodiment, when a position of the entry opening of the fuel injection orifice is changed. Furthermore, in FIG. **8** and FIG. **9**, the horizontal axis represents a ratio of a shift amount in an opening position of the entry opening **220***i* with respect to a diameter of the swirl chamber **212**.

As found from FIG. **8** and FIG. **9**, when the opening position of the entry opening **220***i* is shifted, the spray angle largely changes, but the flow volume hardly changes. That is, according to the structure of the present embodiment, even if the spray angle is adjusted after the fuel injection amount is adjusted, the spray angle can be adjusted without changing the fuel injection amount. Furthermore, from FIG. **9**, it is found that the spray angle gets narrow by shifting the center O**2** of the entry opening **220***i* toward the area A**3** side.

In the present embodiment, it is possible to adjust the spray angle in the fuel spray by shifting the center O**2** of the entry opening **220***i* toward the area A**3** and arranging it, after the fuel injection amount is determined by adjusting the protrusive degree of the entry opening **220***i* of the fuel injection orifice **220** toward the area A**1** side. Therefore, to adjust the fuel injection amount and the spray angle is made to be easy, so design freedom of the fuel injection valve can be improved.

In a comparative example, a fuel flow, which flows into the fuel injection orifice **220'** from the swirl chamber **212'** and is jetted from the fuel injection orifice **220'**, will be explained with reference to FIG. **10** and FIG. **11**. FIG. **10** is a plan view showing a configuration of a transverse passage, a swirl chamber, and a fuel injection orifice in a comparative example. FIG. **11** is a drawing showing an analytical result of a fuel flow at a cross section taken along a line VII-VII in FIG. **10**.

As for the comparative example shown in FIG. **10**, the whole of an entry opening **220***i*' of the fuel injection orifice **220'** is located at the area A**1** side with respect to the extension line (second extension line) **211***il* of the side wall **211***i*. That is, the second extension line **211***il* doesn't intersect the opening edge **212***ic*' of the entry opening **220***i*. In this case, the fuel flow provided with the swirl force flows throughout an entire circumference of the entry opening **220***i*' of the fuel injection orifice **220'**. Because of this, in the case of the comparative example, as shown in FIG. **11**, as the spray form, the spray angle and the fuel flow velocity in a **701** side and the spray angle and the fuel flow velocity in a **702** side are equal to each other.

In the present embodiment, in the **501** side, since the swirl force of the fuel flow is weak, an atomization effect using the swirl force is reduced. However, since the center axis **220***lcl*' direction velocity is high, an atomization performance can be prevented from lowering, or can be kept or improved by using frictional heat between the fuel flow and the air. Accordingly, in the present embodiment, it is possible to readily adjust the fuel injection amount while suppressing the lowering of the atomization performance. Furthermore, as described above, although the spray form of the fuel (the angle and size of the spray or droplet) is changed, as compared with a case where cross-sectional areas of the transverse passage **211** and the fuel injection orifice **220** are changed in order to adjust the fuel flow volume, a change amount of the spray form can be small.

The entry opening **212***i* of the fuel injection orifice **220** is protruded toward the area A**1** side, and the protrusive degree is modified. Thereby, the fuel injection amount can be adjusted. Here, when to adjust the spray angle is required, the protrusive degree to the area A**1** side in the entry opening **212***i* is modified in order to adjust the spray angle, and thereby, the fuel injection amount is also changed. If design of an orifice diameter of the fuel injection orifice, length of the fuel injection orifice, a size (diameter) of the swirl chamber, etc. is redone in order to adjust both of the fuel injection amount and the spray angle, considerable labor and time are needed.

Hereinafter, a modified example where the shape of the swirl chamber **212** according to the present invention will be explained with reference to FIGS. **12** to **14**.

In FIG. **4**, the inner circumferential wall **212***c* of the swirl chamber **212** is formed into a perfect circle. However, as shown in FIG. **12** to FIG. **14**, the inner circumferential wall **212***c* of the swirl chamber **212** may be formed into a spiral shape such as a spiral curve or an involute curve. Furthermore, in case that the inner circumferential wall **212***c* is formed with the spiral curve, the center O**1** of the swirl chamber **212** corresponds to a swirl center of the spiral curve. Furthermore, in case that the inner circumferential wall **212***c* is formed with the involute curve, the center O**1** of the swirl chamber **212** corresponds to a center of a base circle. In this manner, the center O**1** of the swirl chamber **212** is defined as a geometric center or a center of circle set for construction.

FIG. **12** is a plan view enlargedly showing a swirl chamber and a fuel injection orifice in an example where a shape of the swirl chamber is modified (the enlarged plan view of IV area in FIG. **3**).

The inner circumferential wall **212***c* of the swirl chamber **212** in the present embodiment is formed with a spiral curve or an involute curve. The second extension line **211***il*, the areas A**1** to A**4**, and the imaginary line segments L**1**, L**2** are defined as well as in FIG. **4**. In FIG. **12**, the entry opening **220***i* in case that the center O**2** of the entry opening **220***i* of the fuel injection orifice **220** is arranged on the center O**1** of the swirl chamber **212** is shown with a broken line.

The entry opening **220***i* of the fuel injection orifice **220** is protruded toward the area A**1** side over the second extension line **211***il*. Therefore, the second extension line **211***il* intersects with the entry opening edge **220***ic* of the fuel injection orifice **220** at two intersection points **220***ia* and **220***ib*.

Furthermore, the center O**2** of the entry opening **220***i* of the fuel injection orifice **220** is located at a position separated from the center O**1** of the swirl chamber **212**, and arranged in the area A**3**. As well as in FIG. **4**, there is a substantially distance between the imaginary line segment L**1** and the imaginary line segment L**2**, and they have a parallel relationship each other.

Although the center O**2** of the entry opening **220***i* is arranged in the area A**3**, it is disposed in the intersection point **212***ci* side with respect to a center point O**4** which divides a distance between the intersection point **212***cg* and the intersection point **212***ci* into two equal parts on the line segment L**4**. The line segment L**4** is an imaginary line segment which passes through the center O**1** of the swirl chamber **212** and the center O**2** of the entry opening **220***i*, and is parallel to the second extension line **211***il*. Although there is no need that the imaginary line segment L**4** and the second extension line **211***il* are parallel each other, hereinafter the case where the imaginary line segment L**4** and the second extension line **211***il* are parallel each other will be explained.

In the present example, the center O**2** of the entry opening **220***i* is located at a position separated from the center O**1** of the swirl chamber **212**, and arranged in the area A**3**. However, in flow passage width W**21** and W**22**, which are formed in both sides of the entry opening **220***i* on the second extension line **211***il*, the flow passage width W**22** is larger than the flow passage width W**21**. The flow passage width W**21** is a gap (distance) between the wall ending end portion **212***ce* and the intersection point **220***ia*. The flow passage width W**22** is a gap (distance) between the intersection point **220***ib* and the intersection point **220***cf*. The wall ending end portion **212***ce* and the intersection points **220***ia*, **220***ib*, **220***cf* are defined as well as in FIG. **4**.

In flow passage width W**31** and W**32**, which are formed in both sides of the entry opening **220***i* on the imaginary line segment L**4**, the flow passage width W**32** is larger than the flow passage width W**31**. The flow passage width W**31** is a gap (distance) between the intersection point **212***ci* and the intersection point **220***if*. The flow passage width W**32** is a gap (distance) between the intersection point **220***id* and the intersection point **220***cg*. The intersection points **212***cg* and **212***ci* are intersection points of the imaginary line segment L**4** and the inner circumferential wall **212***c*. The intersection points **212***id* and **212***if* are intersection points of the imaginary line segment L**4** and the entry opening edge **220***ic*.

Furthermore, in the present example, a flow passage width W**11** and W**12**, which cannot be defined in FIG. **4**, can be defined. The flow passage width W**11** and W**12** are formed in both sides of the entry opening **220***i* on a line segment L**5**. The flow passage width W**12** is larger than the flow passage width W**11**. The line segment L**5** is an imaginary line segment which passes through the center O**2** of the entry opening **220***i* and the center **21***no* of the nozzle plate **21***n*. The flow passage width W**11** is a gap (distance) between the intersection point **212***cj* and the intersection point **220***ig*. The flow passage width W**12** is a gap (distance) between the intersection point **212***ie* and the intersection point **220***ch*. The intersection points **212***ch* and **212***cj* are intersection points of the imaginary line segment L**4** and the inner circumferential wall **212***c*. The intersection points **220***ie* and **220***ig* are intersection points of the imaginary line segment L**4** and the entry opening edge **220***ic*.

Also according to the structure of the present example, the same effect as the structure in FIG. **4** can be obtained.

FIG. **13** is a plan view showing an example where a position of the fuel injection valve with respect to the swirl chamber is changed in the modified example of FIG. **12**. The second extension line **211***il*, the areas A**1** to A**4**, and the imaginary line segments L**1**, L**2** are defined as well as in FIG. **4**. Furthermore, the imaginary line segments L**4**, L**5**, and the flow passage width W**11**, W**12**, W**21**, W**22**, W**31**, W**32** are defined as well as in FIG. **12**.

In the present example, the center of the fuel injection orifice **220** is further shifted from a position of the center O**2** to a position of the center O**3**. In FIG. **13**, the entry opening **220***i* in case that the center of the entry opening **220***i* of the fuel injection orifice **220** is located at the position of O**2** in FIG. **12** is shown with a broken line. Furthermore, the line segment L**3** is an imaginary line segment which passes through the center O**3** of the fuel injection orifice **220** and a perpendicular line segment to the second extension line **211***il*.

The center O**3** of the entry opening **220***i* is arranged in the area A**3** and in the intersection point **212***cf* side with respect to the center O**4**, which divides a distance between the intersection point **212***cf* and the wall ending end portion **212***ce* into two equal parts on the line segment L**4**.

In the present example, the flow passage width W**22** is smaller than the flow passage width W**21**. The flow passage width W**12** is smaller than the flow passage width W**11**. The flow passage width W**32** is smaller than the flow passage width W**31**. In this manner, even if the inner circumferential wall **212***c* of the swirl chamber **212** is formed with a spiral curve or an involute curve, it is possible that the flow passage width W**12**, W**22**, or W**32** is small with respect to the flow passage width W**11**, W**21**, or W**31**.

Also according to the structure of the present example, the same effect as the structure in FIG. **4** can be obtained.

FIG. **14** is a plan view enlargedly showing the swirl chamber and the fuel injection orifice in the example where the shape of the swirl chamber is further modified (the enlarged plan view of IV area in FIG. **3**). The second extension line **211***il*, the areas A**1** to A**4**, and the imaginary line segments L**1**, L**2** are defined as well as in FIG. **4**. Furthermore, the imaginary line segments L**4**, L**5**, the flow passage width W**11**, W**12**, W**31**, W**32**, and the center point O**4** are defined as well as in FIG. **12**.

The inner circumferential wall **212***c* of the swirl chamber **212** in the present example is formed with a spiral curve or an involute curve. However, the whole of an entry opening **220***i* of the fuel injection orifice **220** is formed in the center O**1** side of the swirl chamber **212** with respect to the second extension line **211***il*.

In such a form, the flow passage width W**21** and W**22** cannot be defined. However, the flow passage width W**11**, W**12**, W**21**, and W**22** can be defined as well as in FIG. **12** and FIG. **13**. Furthermore, in the flow passage width W**11** and W**12**, the flow passage width W**12** can be large or small with respect to the flow passage width W**11**. Furthermore, in the flow passage width W**31** and W**32**, the flow passage width W**32** can be large or small with respect to the flow passage width W**31**. Regarding to the large/small relation among the flow passage width W**11**, W**12**, W**21**, and W**22**, the relation is determined depend on a positional relation of the center O**2** of the entry opening **220***i* with respect to the center point O**4**, and is the same relation as in FIG. **12** and FIG. **13**.

In the case of the present example, an effect of adjusting a flow volume depending on protruding the entry opening **220***i* of the fuel injection orifice **220** toward the area A**1** side cannot be obtained. However, by arranging the center of the entry opening **220***i* of the fuel injection orifice **220** in the area A**3** side, an effect of narrowing the spray angle or an effect of adjusting the spray angle can be obtained.

Furthermore, all of the line segments L**1** to L**5** described above are straight lines.

In a comparative example in FIG. **10**, the entry opening **220***i*' of the fuel injection orifice **220'** is arranged so that its center O**2'** corresponds to the center O**1'** of the swirl chamber **212'**. Thereby, it is possible to maximize a velocity component in the swirl direction of the fuel flowing into the fuel injection orifice **220'**. On the other hand, in the embodiment and the modified example described above, the center O**2** of the entry opening **220***i* is shifted from the center O**1** (first position) of the swirl chamber **212** to a second position, and arranged. The first position is where the velocity component in the swirl direction of the fuel can be maximized. The second position is where the velocity component in the swirl direction is reduced, and where a velocity component in a center axis line **220***cl* direction of the fuel injection orifice **220** is enhanced. Thereby, rectilinearity of the fuel having flowed into the fuel injection orifice is improved, so the spray angle can be made narrow.

The internal combustion engine in which the fuel injection valve of the present invention is mounted will be explained with reference to FIG. **15**. FIG. **15** is a cross section of the internal combustion engine in which the fuel injection valve **1** is mounted.

A cylinder **102** is formed in an engine block **101** of an internal combustion engine **100**, and an intake port **103** and an exhaust port **104** are provided at a top of the cylinder **102**. The intake port **103** is provided with an intake valve **105** that opens/closes the intake port **103**. The exhaust port **104** is provided with an exhaust valve **106** that opens/closes the exhaust port **104**. An intake pipe **108** is connected to an entry side end portion **107***a* of an intake passage **107** that is formed at the engine block **101** and communicates with the intake port **103**.

A fuel pipe **110** is connected to the fuel supply port **2** (see FIG. **1**) of the fuel injection valve **1**.

A fixing portion **109** for the fuel injection valve **1** is formed at the intake pipe **108**, and the fixing portion **109** is provided with an insertion port **109***a* into which the fuel injection valve **1** is inserted. The insertion port **109***a* penetrates the intake pipe **108** up to an inner wall surface (intake passage) of the intake pipe **108**, and the fuel jetted from the fuel injection valve **1** inserted in the insertion port **109***a* is jetted into the intake passage. In a case of two-direction spray, a target is an internal combustion engine having a form where two intake ports **103** are provided at the engine block **101**, and the fuel sprays are injected toward each intake port **103** (each intake valve **105**).

The present invention is not limited to the above embodiment or modification example although having been explained above on the basis of them. Therefore, a part of the configuration could be removed, or another element that is not disclosed in the above embodiment or modification example could be added. Furthermore, in the embodiment and the modification example, the element that is disclosed in the above embodiment or modification example can be changed or added.

The invention claimed is:

1. A fuel injection valve comprising:

a valve body;

a fuel injection orifice provided in a downstream side of a valve seat which the valve body is structured to move toward and away from;

a swirl chamber having a bottom surface on which an entry opening of the fuel injection orifice is configured to open and an inner circumferential wall surrounding the bottom surface, the swirl chamber having:

a swirl passage for fuel, the swirl passage formed between the inner circumferential wall and the entry opening; and

a transverse passage whose downstream end is opened in the inner circumferential wall of the swirl chamber in order to provide the fuel into the swirl chamber, the transverse passage having:

one side wall connected to an upstream side of the inner circumferential wall in a flow direction of swirling fuel; and

another side wall connected to a downstream side of the inner circumferential wall in the flow direction of the swirling fuel, and

wherein an extension line formed by extending the another side wall of the transverse passage to a swirl chamber side, and a straight line segment passing a center of the swirl chamber and being perpendicular to the extension line are arranged such that a center of the entry opening of the fuel injection orifice is shifted from the center of the swirl chamber along the extension line, and in two areas formed by dividing the swirl chamber into two with the straight line segment, the center of the entry opening of the fuel injection orifice is arranged in an area opposite to an area to which the transverse passage is connected.

2. The fuel injection valve as claimed in claim **1**, wherein: a first line segment passing the center of the entry opening and parallel to the extension line intersects with an opening edge of the entry opening at two points.

3. The fuel injection valve as claimed in claim **2**, wherein: a first flow passage width and a second flow passage width are formed at respective sides of the entry opening on the first line segment, and

the first flow passage width, which is at the upstream side in the flow direction of the swirling fuel, is smaller than the second flow passage width, which is at the downstream side in the flow direction of the swirling fuel.

4. The fuel injection valve as claimed in claim **3**, wherein: the inner circumferential wall of the swirl chamber has an arc surface having a constant radius.

5. The fuel injection valve as claimed in claim **4**, wherein: the center of the swirl chamber is on the first line segment, and the first line segment corresponds with the extension line.

6. The fuel injection valve as claimed in claim **2**, wherein: the inner circumferential wall of the swirl chamber is formed with a spiral curve or an involute curve.

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